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Proceedings of the Fifth Naval Training Device Center and Industry Conference

ABSTRACT

A compilation of papers on a variety of technical and training subjects relating to training device technology and training methodology. These papers were presented at the Fifth Naval Training Device Center and Industry Conference held at the Contemporary Hotel, Walt Disney World, Orlando, Florida, February 15-17, 1972.

The conference theme "Twenty-five Years of Training Simulation—Springboard for the Future," provided a common ground for the exchange of new ideas and discussion of mutual problems. This fifth conference is part of a continuing program to encourage and develop better liaison between the Naval Training Device Center and the training simulation industry.

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FOREWORD

During the past twenty-five years the Naval Training Device Center, together with the training device industry, has developed a continuously advancing training simulation technology to meet the ever expanding training needs for the warfare areas of the Navy, the Army, and the Marine Corps.

As the Naval Training Device Center goes into its second quarter of a century of partnership with the training device industry, the need for an acceleration in the advancement of training technology becomes more and more pressing. We are sure that the achievements of the past twenty-five years form a good basis for industry's and our own future endeavors to meet the demands of the user, and that these achievements justify the theme for this year's conference—"Twenty-five Years of Training Simulation—Springboard for the Future".

As in the past conferences, much can, and will be accomplished if frank and open discussion continues. By the exchange of ideas and active participation in efforts of common interest, industry can greatly contribute to achieving the goals placed on the Naval Training Device Center, and the U.S. Army Training Device Agency by the combat forces of the Navy, the Marine Corps, and the Army.

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Technical Director and
Conference General Chairman

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Commanding Officer, Naval Training Device Center

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Conference General Chairman

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TABLE OF CONTENTS

SESSION IV (continued)

SESSION V

SESSION VI

PAPERS PUBLISHED, BUT NOT PRESENTED

PAPERS PUBLISHED, BUT NOT PRESENTED (continued)

CONFERENCE THEME

DR. H. H. WOLFF
Technical Director, Naval Training Device Center and
Conference General Chairman

Military training is as old as organized society. For many centuries, it was conducted in the real environment using real military hardware. Gradually, however, mainly in the first quarter of this century simulation was introduced. For example, special exercise ammunition was developed and the new weapons platform, the tank, was simulated.

The years between the two world wars and especially World War II itself brought a basic change in military training. It was in that period that our Navy started to replace training in the real environment by training in a simulated environment, by means of training devices, and training device technology and training methodology started to develop into a science and a technique.

We, here at the Naval Training Device Center, had, last year, the pleasure of commemorating the 30th year of the Navy's Training Device involvement, and the 25th Anniversary of the establishment of the first specialized Training Materiel Command.

The increase in complexity of modern warfare, especially multiplatform warfare, and the resultant need for training in simulated multiplatform settings resulted in the need for a vast variety of training programs to train for the many different skills needed in modern warfare. Naturally, this large variety of training problems caused a large variety of training activities to get involved in different aspects of the Navy's training needs and resulted in a fragmentation of the Navy's training program. It became more and more obvious that a coordination and unification of all these various training programs was mandatory if the Navy wanted to achieve the highest quality of training. This demand has led the Chief of Naval Operations to reorganize the Navy's training efforts by placing all training other than that assigned to the Fleet Commanders and the Chief, Bureau of Medicine and Surgery, under the newly established Office of Chief of Naval Training.

This reorganization will make it possible not only to provide an all encompassing and more effective unified training program for all of the Navy's present and future warfare situations, but will also achieve through cross-fertilization between different training areas a vastly improved training program and thereby an improvement in the professional capabilities of all Navy personnel.

Those of you who have been associated with military training, since the establishment of this organization, or even have been associated earlier with the initial phases of synthetic training, when RADM (then CDR) Luis de Florez became the first deskholder for training material in the Navy, know that training material has come a long way since the days of the 610 H Street NE Washington garage.

Starting with simple straight forward technology, we have reached today a point when even the most advanced technology available does no longer satisfy the needs of the Navy's training activities.

Operational equipment is getting increasingly complex. Its operation requires more and higher skill. And, consequently training devices call for higher and higher sophistication.

As most of you know, the Naval Training Device Center, and the training device industry have — during the last decade — made vigorous attacks on the state-of-the-art in training device technology, especially in the areas of visual environment simulation and in radar and sonar training simulation.

In spite of many achievements of the past, many areas of training device technology, especially systems for flight and ship control training, for sonar and radar for team and for task force training, to name a few, call for further advances, if we want to achieve training that is cost-effective as compared to training in the real environment, if we want to achieve the training goals in the shortest amount of time, and if we want to achieve these goals with equipment that minimizes the cradle to grave overall cost, and that minimizes the human resources needed for its operation and its maintenance.

The problems that existed six years ago made us aware of the fact that a closer cooperation between NAVTRADEVCEN and industry was needed. They have led to the first NAVTRADEVCEN/Industry Conference, which Captain Jack Sloatman, who was at that time our Commanding Officer, personally vivaciously promoted.

We open today the Fifth NAVTRADEVCEN/Industry Conference under the Command of Captain Frank Featherston, who was the driving force for having this Anniversary Conference here in Walt Disney World. As you may know, conferences of this type; especially, in today's financial environment —require high-level approval which can be obtained only if the Command is wholeheartedly promoting it, and all of us at NAVTRADEVCEN are very happy that Captain Featherston could convince our parent Command of the importance of our NAVTRADEVCEN/Industry Conferences for a continued progress in the support of the Navy's training program.

Looking back over the years that have passed since our first conference we find that many advances have been made during this time span.

In our first conference, I talked to you about our concern over the extensive cost and time spent for the reliability test of one-of-a-kind training devices and proposed new approaches to cope with this problem. Several of our reliability people have attacked this problem since then as most of you know with considerable success. For, whereas five years ago we required a test time of approximately 250 hours, with a possibility of running up to close to 500 hours, today we can often satisfy our reliability conscience in a 40-hour test. Five years ago we tested under an unrealistic continuous operation. Today, we go through a realistic operational cycle, and have begun to operate the equipment under test in accordance with a realistic lesson plan such that the test corresponds as much as possible to the actual usage. Five years ago we did not distinguish failures as to their criticality in the training program. Today, we assign weights to failures and provide thereby a much better basis for a meaningful reliability acceptance test.

In the 1967 conference we discussed the importance of the value engineering program. With the cooperation of the industry, we have achieved considerable annual savings for the Government and thereby the taxpayer. During the last fiscal year, for example, $659,000 were saved under this program.

In the 1967 conference I mentioned to you also the need for automatic failure indicator systems. Unfortunately, I cannot report here any significant progress. This is, therefore, a call for investigations into how to take advantage of the state-of-the-art in automatic failure indicators, and automatic testing, and for a possible promotion of the state-of-the-art where it is needed, certainly good fields for industry's Independent R&D Program.

Finally, I had asked, in our 1967 conference, to pay more attention to the instructor and trainee problem in the development of training devices, rather than to be satisfied simply with the simulation of operational equipment.

I renewed this request in our 1968 conference, asking especially to strive for an improvement in the student to instructor ratio. Industry has responded to this need.

For, we have meanwhile procured and are presently under new procurements for training devices in which the instructor is enabled to handle several students simultaneously, both through an automatic adaptation of the difficulty of the training task to the trainee's performance and through the use of cathode ray tubes for on-call displays of instruments and performance parameters. You will find these concepts increasingly called out in the specifications for future flight trainers and others.

In the 1968 conference, in addition to the repeated request for automatic failure indicators, I asked for self-healing systems. This again should be a good problem for industry's independent R&D Program, especially for companies that are also involved in the space program.

In our 1969 conference we talked about a diversity of problems, problems in training psychology, trainer technology and trainer procurement, many of which are still unresolved; especially the automatic evaluation of student performance, adaptation steps in adaptive systems, physiological factors in training (a very broad field), the various areas of visual simulation, such as computer-generated displays, for example radar displays, as well as many others, still pose problems.

For several years we have tried to reduce training device cost, maintenance cost, spare parts inventory and maintenance skill requirements by an aggressive standardization program. I would like to take this opportunity to acknowledge the contributions that our industry has made to this effort, especially through the sub-committee on training device component/equipment standardization of the National Security Industrial Association.

As a result of our standardization effort the number of waivers for non-standard parts has tremendously decreased, offeror's standardization efforts are evaluated as to their compliance with standardization plans such as the MIL-T-23991 specification, the NAVAIR Avionics preferred standard test equipment list and others.

Very shortly a cockpit procedures trainer procurement will be used to evaluate the applicability of the Navy's standard hardware program to training devices, and in the next fiscal year we intend to specify the use of SHP (Standard Hardware Program) modules for a major training device, just to mention a few of our plans to promote standardization.

Let me turn now to a few problems that have not yet been brought to the forefront.

The need to replace more actual flight time by training device time has resulted in a demand for flight trainers of more encompassing simulation features, trainers that provide both motion and visual environment simulation. Since a motion platform can provide only a limited motion simulation; namely, an acceleration and a deceleration onset, a wash-out has to be provided. As a consequence of this, any motion platform position may represent different operational platform (for example aircraft) positions, each of which demands a different visual presentation of the visual environment. The difference in the limitations of motion simulation and visual simulation prevent a perfect solution for the linkage between motion and visual display. We will have to be satisfied with a deficiency minimization. Though some experiments have been conducted in this field much more knowledge is required about the motion inputs that different vehicles provide to the human sensory system and for which we have to provide motion simulation. A multidisciplinary R&D effort is needed here before we have the technology well enough in hand to avoid negative training and satisfy the user.

Maintenance training was for many years a simple device problem. Operational equipment was cut apart and provided the hardware needed by the instructor for his lecture. With increasing complexity of operational equipment to be maintained, maintenance training cannot be effectively undertaken any more by using operational hardware. Very little effort has been directed towards increasing the training effectiveness in this area by better maintenance training devices. A few new approaches are reflected in the new generalized sonar maintenance trainers which we procured for the school in Memphis. The Chief of Naval Training, and the Chief of Naval Technical Training are looking at us and at the trainer industry to provide the means for vastly improved maintenance training material.

All of us know that in spite of the many advances that have been made we are still behind the demands of the users. These demands have increased in sophistication faster than the state-of-the-art progressed. This holds true as much for training methodology as it does for hardware, especially for totally integrated multiunit task force systems.

Today's operational systems offer such a tremendous versatility of utilization that only extremely well-trained personnel are able to fully utilize the system capability. This means that the training programs have to be very carefully developed and standardized to assure the use of the most effective training methodology.

In future larger procurements—especially of weapons systems trainers—you will find, therefore, increasingly that a detailed course outline and a training syllabus are mandatory deliverable items.

Let me take up another subject which we should vigorously attack.

We have about 550 million dollars worth of training devices in the Navy inventory and it has been estimated that we have in the training program close to two billion dollars worth of operational equipment that has been set aside for training purposes. Assuming that this operational equipment will have to be replaced over a 10-year span, about 200 million dollars will be spent annually for such equipment. You can analyze for yourself how much of this equipment could be replaced by training devices that are more training effective

and far less costly, and how much the training device market could broaden and how much taxpayer's money could be saved if all of us would take steps to build-up this area more aggressively.

As you can readily see, much has been achieved in the last 25 years, much more is ahead of us, only part of which I could outline to you. But based on these past achievements, both within NAVTRADEVCEN and in industry, we feel that our first 25 years in the training device business form an excellent springboard for the future.

As you know, NAVTRADEVCEN is a multiservice activity for we not only serve the Navy, but also the Army through the U.S. Army Training Device Agency under Colonel Mierswa, and the Marine Corps, that through Colonel John Terry, the Marine Corps Liaison Officer, is rapidly increasing its training device involvement. Finally, we often have the privilege to assist the Air Force in meeting its training device requirements.

I am very happy to welcome all our friends from the Navy, the Army, the Marine Corps, and the Air Force, and last, but not least, from our industry.

WHAT'S HAPPENING IN TODAY'S ARMY

General Ralph E. Haines, Jr.
Commanding General, U.S. Continental Army Command
Fort Monroe, Virginia

I'm happy to be here on the Silver Anniversary of the Naval Training Device Center and gratified that this conference offers the opportunity for the services and industry to focus attention on the past 25 years of training simulation as a springboard for the future.

In acknowledging the 25th Anniversary of the Naval Training Device Center, I am pleased to note that this has been a cooperative effort with the Army participating for the last 21 years. The Army is appreciative for the excellent support that has been provided our training during this time. You are to be commended for your fine work.

My purpose here today is to tell you "What's Happening in Today's Army"—with particular reference to the innovations in the Army's training programs, and later in my discussion pass on to you information concerning the Modern Volunteer Army Program.

First, I would like to say that the Continental Army Command (CONARC), with its 13 training centers, at which newly recruited or drafted soldiers receive their initial training, and the 24 Army Schools, which train and educate officers and enlisted men to various levels of skill or knowledge, has

the largest training responsibility of any U.S. Command world-wide. At the end of FY 71, there were nearly 367,000 individuals trained in Basic Combat Training (BCT), 291,000 in Advanced Individual Training (AIT), and 271,000 in the service schools, for a total of 928,000. So you can see CONARC's mission as the Army trainer is sizeable. CONARC is responsible for determining training aids and device requirements, and operating the CONUS training aid center system. The Training Centers and Army Schools, which constitute the "training base", and the major users of training devices, today faces a dichotomy of effort deriving from the necessity to reorient our training toward requirements in other parts of the world, and yet continue to provide maximum support to Vietnam. The country is psychologically in a post-war period even though we are still heavily involved in a shooting war. Our training dollars have been decreased by budget constraints, with no reduction in mission, to maintain a high-level of combat readiness. As a result, a great deal of command emphasis from the Chief of Staff of the Army, down through major commands, is being exerted to make maximum use of training devices in lieu of the actual weapon or item of equipment where effective training can be accomplished, and cost savings accrued.

Our primary aim must be the effective discharge of our responsibilities for the defense of our country. By that, I mean that we train in the skills that relate directly to military duties and employ all means provided by science and industry toward the accomplishment of this training.

Our training programs are under continuous review, revision, and refinement. We place high priority on keeping them current and attuned to changing needs. The objective is to assure that these programs remain vigorous and challenging for our young soldiers.

At our 13 U.S. Army Training Centers, each inductee entering the Army receives an eight-week Basic Training Course covering the military fundamentals that all trainees must have. Upon completion of basic training, about 70% of the trainees remain in the Training Center System for eight or more additional weeks, and receive Advanced Individual Training or AIT in one of the 69 military skills taught in that system. Another 20% of the basic training graduates proceed to Army Schools for AIT in one of approximately 178 skill-producing courses, the longest of which takes a full year to complete. The remaining 10% of basic training graduates go directly to units to complete their skill qualification by on-the-job apprentice-type training, or to a duty position for which they are already qualified by reason of their civilian education or experience.

We are making changes in AIT with increasing emphasis on hands-on training and performance testing.

The content and nature of Army education and training is, I contend, scientific, because it applies "expert knowledge and technical skill" in its theory and in its practice. But, we also attempt to apply scientific methods in the accomplishment of this training. The Army's interest in training technology stems from the need to improve training, and produce a more skilled soldier in less time and at a lower cost. Several years ago, we decided that the base process upon which our training must be developed is the systems approach. After thorough study and preparation, we established a five-year program through which all courses at our Army Schools and Training Centers will be systems engineered.

In this process, the first and most important step is job analysis, which identifies the on-the-job performance requirements in terms of individual tasks and characteristics of various duty positions. During job analysis, our schools conduct interviews with job incumbents and use the output of the military occupational data bank, which is a computerized repository of detailed job and task data collected from questionnaires administered on an Army-wide basis. These data indicate job frequency and help determine what training is required. In the second step of systems engineering, essential tasks are selected for training and then are evaluated to determine whether they should be taught in a formal course of instruction or accomplished by on-the-job training. In succeeding steps, tasks are converted into training objectives and training materials to include training aids and device requirements and tests are prepared. Quality control is the last step of the process. Test results are analyzed and feedback information is obtained by observation and reports from commanders and course graduates. By these means, courses are continually evaluated and updated.

The systems engineering approach to training is fundamental to insuring that course content and training methods develop soldiers who can perform successfully on the job. The systems approach is also the vehicle for capitalizing upon the advantages of other training innovations, as it guarantees that all of them receive full consideration in course design and development.

As a matter of information, CONARC uses programmed instruction throughout the Army School system. This is a self-paced method of teaching through the use of specially prepared texts which provide instant feedback to the student and thus assures progress at his individual rate. Our analysis of programmed instruction has shown that most students, who have difficulty learning from a classroom instructor, are better able to absorb and retain knowledge through texts.

A natural extension of the use of programmed texts in particular segments of instruction is their use in completely self-paced courses. Our Helicopter Instrument Flight Course has been completely converted to self-paced instruction by allowing students to progress at their own rate instead of in lock step. An average savings of two weeks in training time was achieved; additionally the dollar savings accrued were sufficient to amortize the total contract cost by the end of the first year of operation.

Presently, the Army has a number of training programs that utilize computer-supported instruction. Based on our experience, we have found that the computer can be a most valuable tool in both the active instructional process as well as in the administration and management areas. CONARC exercises a progressive development policy, which encourages investigation, into discrete applications of the computer in support of training functions.

A final example of our educational innovations is our extensive use of Educational Television, or ETV. Closed circuit educational television is used at all 24 of our Army Schools and 10 of our Training Centers, with taped material ranging from basic training subjects to complex military problems.

We derive many advantages from use of television. We realize significant savings in equipment and manpower costs by taping live performances for repetitive instruction. Other benefits include the ability to standardize instruction and to preserve noteworthy presentations otherwise available to only a few students on a one-time basis.

In addition to producing instructional tapes for television viewing, our television production facilities support the Army-wide training film program. TV tapes are converted to 16mm film for Army-wide distribution. These are but a few highlights of the many changes taking place in the Training Centers and Service School training programs in today's Army.

Now turning for a moment to future developments in the area of training simulation. In the past, the Army has made considerable use of training aids and devices in the Missile, Armor, Infantry, Artillery, and Aviation fields. However, we have scarcely touched on simulation for the Combined Arms Tactical Training Programs. The shrinking land area available for large scale maneuvers, the requirement to improve training effectiveness, and reduce training cost, requires us to look to simulation to solve our most critical tactical training problems. In this respect we have initiated a requirement to develop a Combined Arms Tactical Training Simulator (CATTS). The purpose of the CATTS will be to simulate a variety of combat situations for the training of future commanders and staff officers. The primary requirement is to realistically approximate the placement of a commander and his staff in either of two simulated combat options, a ground command post environment for conduct of tactical ground operations, or a command and control helicopter environment for conduct of airmobile tactical operations. We are looking forward to the simulator as the long-range solution to one of our many training problems. As many of you know, our most prestigious trainer to date is the Synthetic Flight Trainer System now undergoing test at Ft. Rucker. This, the Army's most ambitious and costly trainer development program represents a move from the horse and buggy days and into the space age for instrument flight training. We believe that the future cost savings potential will be very significant not only in flying hours saved, but in better trained aviators.

While any review of the total training devices and training aids picture reveals that many requirements are initiated by the people at the local Training Centers and Schools, I am aware that many are developed by industry or the laboratory, and I am well aware of the part you play in the initiation and development of our requirements. We must always be on the alert for new innovations, new developments, and most of all, new ideas on how to improve the training of our modern Army.

This leads me to another major innovation that is taking place today—that of the Modern Volunteer Army. The Chief of Staff has directed the Army to move without delay to build a more professional Army with a zero draft and to achieve this by 1 July 1973. The program was kicked off officially by General Westmoreland at his Commanders' Conference, 30 November 1970.

The Modern Volunteer Army Program consists, in general terms, of three categories of actions or initiatives, with purposes described as—

Strengthening Professionalism
Improving Attractiveness of Army Life
Enhancing Public Respect for the Soldier.

Inherent in this combination of categories is the will to promote the most effective and efficient means of mission performance; to improve the life-style and living conditions of the soldier and his family, and to enhance the respect of the soldier for himself and in the eyes of the American public. Through accomplishments in each of these areas we are striving to attain the goal of a better Army and eliminate reliance on the draft.

The Modern Volunteer Army (MVA) Program began last November when several high impact actions, such as elimination of reveille, more liberal pass policies, and a shorter work-week were adopted Army-wide. Numerous actions designed to enhance training, improve living and working conditions, and eliminate the non-essential, so that we may get on with the necessary aspects of duties, have since been implemented. Within the context of each of these actions, I want to emphasize that we seek first to build a highly professional, disciplined Army capable of survival and victory on the battlefield.

As an integral part of the MVA Program, test experiments, under the title of Project VOLAR (VOLAR being the acronymn for Volunteer Army), are being conducted at selected Army installations. The purpose of these experiments is to test and determine those improvements or changes which, when implemented Army-wide, will enhance the military posture and increase enlistments and re-enlistments. Four CONARC installations took part in the Project VOLAR experiments during FY 71. During FY 72 we are expanding these experiments and a total of 13 Army Posts, within the Continental United States, will be participating.

To achieve our goal of a highly professional volunteer force in FY 73, we must increase enlistments and reenlistments significantly. To assist in accomplishing this, the attractiveness of the service must be increased together with a decided improvement in the Army's combat capabilities.

I am sure that you have seen reports in the local papers of many of the specific measures we are taking in these areas. We have solicited ideas from a broad spectrum of Army personnel and are currently in a testing period, trying out ideas, which we consider have merit. These tests are at selected locations and conducted under carefully controlled conditions. Changes are always difficult, particularly in a stable institution such as the Army, and especially when they impinge upon proven methods. But times are changing; and we must be responsive to social change, without compromising basic values, if we hope to remain in contact with and communicate to the soldiers.

In our efforts to improve the life-style of the soldier and to remove service irritants, we will not impair the ability of the Army to perform its mission. We, in the Continental Army Command, are mindful of our responsibilities and intend to improve the Army's professionalism within the context of the Modern Volunteer Army. This will call for all the talent and judgment at our command.

Regardless of changes we make within the Army, however, we cannot hope to achieve our goals unless we receive support from the Executive Branch of the Government, members of Congress, the news media, and civic, business, and educational leaders.

The goal of acquiring a completely volunteer force is yet to be proven. Certainly we will leave no stone unturned in attaining that goal.

It is important that we keep draft legislation in existence until we can demonstrate conclusively that a Volunteer Army is both feasible and effective in the discharge of its assigned responsibilities. We will, in fact, have a continuing although lessening need for the draft for several years to come. If we are able to shift to a Volunteer Force, we must do it without creating a gap between the Army and the people which we serve. In our zeal to see

those laws enacted, that will provide us with the inducements needed to attract sufficient members of qualified men and women, we must not create a mental climate in which the average citizen feels that he can, in effect, buy his way out of any obligation to defend his nation.

We, in the Army, are faced today with the activism of the "now" generation. I recognize that the local draft board is only one of many institutions to which the youth of today cannot relate easily. Many are skeptical of the values of our society and cynical because of inconsistencies found between stated beliefs and actions which appear to belie those beliefs. One of the lessons learned during research, conducted on the fall of the Roman Empire, is that "a society that loses interest in its Army and distains military service will pay for its mistake sooner or later." I feel that the MVA Program will do much to prevent this conditon from developing in this country.

The Vietnam War weighs heavily on most of us. However, my current responsibilities do not encompass that area and I would prefer to leave to the writers of history the rights or wrongs of our involvement there. I must observe, however, that I find it difficult to accept the thesis of some which, through a strange transposition of fact, has made the aggressor the aggrieved. I do have a feeling of compassion for the young men and women, who return from Vietnam, every day in the year. They merit a far better reception than they are getting from the people of this country. Our most pressing job in CONARC today is to rebuild the dignity, pride, and motivation of the post-Vietnam Army. Again, we will need all the talent and judgment we can muster. After every war there has been a tendency toward a drop in morale, esprit, and prestige for the man in uniform. We must work to overcome this tendency because of its deleterious effect on both the man in uniform and the public. The dedication of the soldier and the confidence of people in him are principal ingredients of our national strength. The nation will be the loser, if over the longer term, the dignity and pride of the soldier are not retained.

I have attempted to outline for you some of the aspects of our education and training requirements and to point out the way the Army is moving today. With shrinking resources and maneuver areas, the Army is placing greater reliance on training aids and devices than at any time heretofore. We cannot be satisfied with our present methods of training. We must constantly search for better, more effective and less expensive solutions to our training problems.

SESSION I

Tuesday, 15 February 1972

Chairman: Dr. James J. Regan
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TRANSFER OF INSTRUMENT TRAINING AND THE SYNTHETIC FLIGHT TRAINING SYSTEM[1]

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INTRODUCTION

The Army's Synthetic Flight Training System (SFTS), Device 2B24, has been referenced in a number of the papers presented here. It is assumed at this point that the reader is generally familiar with overall SFTS design, and the extent to which it incorporates automated training features as well as manual features which can facilitate the conduct of training administered in a non-automated manner. The device is unique in these aspects in the Army's history of training device development.

Army regulations require that newly acquired equipment of the complexity of the SFTS undergo an extensive service test prior to type classification. Type classification is a step necessary to the introduction of such equipment on an Army-wide basis. An important part of service testing involves a determination of the operational suitability of the equipment. In the case of the SFTS, the Human Resources Research Organization's Aviation Division was requested to support the service test, to be conducted by the U.S. Army Test and Evaluation Command, by developing and conducting an SFTS Operational Suitability Test. The test is in progress, and its findings are expected to be released later this fiscal year. The present paper addresses one portion of the SFTS suitability test, that portion dealing specifically with transfer of instrument training from the SFTS to the aircraft.

The fact that the SFTS is unique makes its suitability testing difficult. Since it is not a replacement for existing equipment, and since much of the training possible with it previously has not been possible for the Army, even using operational aircraft, previous approaches to training device suitability testing are inappropriate for the SFTS. A test which failed to build upon the unique features of the device probably would produce evidence of its unsuitability to the Army's requirement. A test which asked of the SFTS no more than is provided by existing Army flight training devices undoubtedly would lead to its rejection on a cost-effectiveness basis. On the other hand, a test which exploited the design-for-training features of the SFTS, with the goal of determining its cost-effectiveness in a training situation, could lead to quite different results.

A three-phase operational suitability test was developed. During Phase I, primary emphasis was placed upon a determination of the workability of the various automatic and semi-automatic training features of the device. During Phase II, a training program was developed which was intended to exploit the

[1] The ideas expressed in this paper are based on research conducted at HumRRO Division No. 6 (Aviation), Fort Rucker, Alabama, under Department of the Army contract; the contents of this paper do not necessarily reflect official opinions or policies of the Department of the Army.

potential of the device in such a manner that developmental hardware deficiencies would have minimum adverse effect upon test results. During the final phase, a transfer of training study was conducted, and a determination was made of the cost-effectiveness of the device in the Army's rotary wing aviator training program. This paper will address only those operational suitability test activities related to a determination of the transfer of instrument training value of the SFTS.

TRAINING PROGRAM DEVELOPMENT

It is generally recognized that the effectiveness of any training program is a joint function of the equipment employed and the manner of its employment. In addition to having a number of unique training features, the SFTS is significantly more comprehensive in its simulation of the training aircraft than is any known equipment used in undergraduate level flight training. Consequently, a training program had to be developed to take advantage of the capabilities it provided with an undergraduate trainee population. That program was developed during Phase II of the SFTS Operational Suitability Test.

The training program was an advanced adaptation of a program previously developed for use with a fixed wing instrument training device. The fixed wing program is described elsewhere and should be referred to by anyone with an interest in the technology of training applied to flight training per se.[(2)] The primary features of the training program developed for the SFTS are:

—conduct of all training within a functional context

—conduct of all training on a proficiency basis

—specification of all training goals in objective, measurable terms

—conduct of all training in the SFTS, not the aircraft

—treatment of the SFTS as an aircraft

—complete individualization of instruction

—redefinition of the role of the instructor pilot

—conduct of crew training

—use of incentive awards

—use of diagnostic progress rides

—use of all features of the SFTS found workable during Phase I.

Time did not permit a pilot study to verify that the SFTS training program had been optimized from the standpoint of efficiency. The overall Service Test schedule required that student training be initiated as soon as practical. Consequently, the program was evolved largely from experience obtained with the

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[2] Caro, Paul W. "An Innovative Instrument Flight Training Program." Paper No. 710480. Society of Automotive Engineers, New York, N.Y., May, 1971.

fixed wing program previously mentioned, with several earlier rotary wing training research programs, the experience of other training organizations, and the general technology of training. The experiences of several commercial airlines were particularly helpful in this regard. As a result, the conduct of student training with the SFTS, Phase III of the Operational Suitability Test, was undertaken with high confidence.

THE TRANSFER OF TRAINING STUDY

EXISTING TRAINING. At the time of the study reported here, Army undergraduate pilot training consisted of four phases—Primary, Instruments, Advanced Contact, and Tactics. The Primary Phase consisted of 110 hours of dual instruction and solo practice in a light, reciprocating engine helicopter, the TH-55. Sixty hours instrument training in a similar aircraft, the TH-13T, plus approximately 26 hours training in an existing instrument training device, a modified 1-CA-1, made up the Instrument Phase. The Advanced Contact Phase consisted of 25 hours transition training in the turbine powered UH-1B, D, or H model helicopter. The final phase of training, the Tactics Phase, consisted of 25 hours training in the UH-1 aircraft. The UH-1 is the primary operational aircraft for the newly graduated Army aviator. His initial assignment typically is to pilot or co-pilot that aircraft.

EXPERIMENTAL TRAINING. The trainees who participated in the SFTS test received the same training, except that all instrument training was administered to them in the SFTS instead of in the TH-13T and the existing devices. Additionally, the UH-1 Contact Phase transition training received by this group was modified to take advantage of training received in the SFTS. Only the results related to the Instrument Phase training are described in this paper. The effects of SFTS training upon transition training requirements are not addressed.

TEST SUBJECTS. Sixteen test subjects participated in this study. They were selected, using a table of random numbers, from among the 34 active Army members of an Officer Rotary Wing Aviator Course who completed the primary phase of training (110 hours contact training in the TH-55) at the time the SFTS training was scheduled to begin and who volunteered to participate in the study. These trainees had no prior instrument flight training and had relatively little flight experience prior to entering the Army pilot training program. The maximum amount of prior flight experience was approximately 60 hours. The majority of the test subjects had received 35 to 40 hours pilot training in an ROTC private pilot training program prior to entering the Army.

INSTRUCTORS. Nine Army Officers, Warrant Officers, and Department of the Army Civilian Instructor Pilots (IPs) participated in this study. Eight of these were assigned two test subjects each, and the ninth was used as a spare in instances of the necessary absence of one of the other instructors. Initially, each instructor was either an Instrument Phase IP or a Contract Phase IP. Consequently, it was necessary to qualify the former in the UH-1 aircraft and to qualify the latter as instrument instructors. This was done by the U.S. Army Aviation School. The instrument training experience of these IPs thus varies considerably. It ranged from no prior instrument instructing experience to extensive IP experience and qualification as an Army instrument examiner.

Prior to the beginning of Phase III, each IP underwent training by the research staff in the manner in which the experimental training program was to be administered in the SFTS. Additionally, their performance was closely monitored throughout the training to encourage compliance with the training program design. These steps were necessary due to the fact that the experimental training program required numerous significant deviations from training practices to which these IPs were accustomed.

In addition to the IPs who conducted the experimental training, the SFTS instructor console was manned by non-rated personnel who assisted the instructors when they were conducting training from inside the cockpits. The chief functions performed by these device operators related to problem set-up and simulated ground station communication.

PROCEDURE. All instrument training was conducted in the SFTS on a proficiency basis. Necessary instrument flight related academic instruction was conducted under the supervision of each trainee's IP, using programed text books. Other training for the test subjects took place with comparable students who were not participating in this study. When the IP determined that his students met all proficiency requirements for award of an Army standard instrument rating, they were sched led for a checkride.

RESULTS

Table 1 indicates the amount of training received by each trainee in the SFTS. At the end of that training, each trainee was administered an instrument checkride by a qualified Army instrument examiner who was not otherwise participating in this study. The time required for conduct of the checkride and the checkride grade are also indicated in table 1. It should be noted that two subjects did not pass the checkride the first time it was administered. In each case, they returned to their assigned IP for additional training and then were given a second checkride, which each then passed. Table 1 includes all training and checkride time required by these students. Army Aviation School policy dictates that the grade of 70 be assigned when any checkride is passed after having once been failed, regardless of the quality of the student's performance on the recheck.

The mean-time required for these students to pass the required instrument checkride in the SFTS was 42:50. Of this, 40:28 was devoted to training, and 2:22 to evaluating their performance during checkrides. This compares with the total training and evaluation time scheduled for all conventionally trained students of 60 hours in the TH-13T, plus 26 hours training time in the modified 1-CA-1 device.

Upon passing the instrument checkride in the SFTS, these experimental trainees were judged qualified, so far as proficiency was concerned, for award of a standard instrument rating. Present Army Regulations, however, require that such an award be made only upon the basis of performance during a checkride conducted in an aircraft. Consequently, the test could not be concluded until these trainees had been examined in the aircraft itself.

Each IP "transitioned" his assigned trainees from the SFTS to an instrument equipped UH-1H. This transition training was conducted under the hood or under actual instrument conditions, i.e., it did not include <u>any</u> contact flight training. (None of the trainees had prior experience flying the UH-1). Table 2 indicates the amount of time devoted to this aircraft familiarization activity. Transition training was restricted to familiarization with the aircraft under simulated or actual instrument conditions, since it was presumed that all necessary instrument training had been conducted in the SFTS.

TABLE 1. TRAINING AND CHECKRIDE TIME REQUIREMENTS AND CHECKRIDE GRADES OF TEST STUDENTS IN THE SFTS

Student Number	Training Time	Checkride Time	Total Time	Checkride Grade
1	33:15	2:15	35:30	89
2	35:00	2:00	37:00	82
3	35:00	2:00	37:00	84
4	37:30	2:00	39:30	73
5[a]	39:00	4:15	43:15	70
6	40:00	2:15	42:15	85
7	40:30	2:15	42:45	90
8	40:45	2:00	42:45	91
9	41:00	2:15	43:15	90
10	42:00	2:00	44:00	94
11	42:15	2:45	45:00	89
12	43:00	2:00	45:00	92
13[a]	43:45	3:30	47:15	70
14	44:00	2:15	46:15	80
15	45:00	2:00	47:00	82
16	45:35	2:00	47:35	86
Mean	40:28	2:22	42:50	84.2
S. D.	3:41	:38	3:47	7.6

[a]Students 5 and 13 did not pass the checkride in the SFTS the first time it was administered. Their performance was satisfactory on a subsequent recheck.

TABLE 2. AIRCRAFT FAMILIARIZATION AND CHECKRIDE TIME REQUIREMENTS AND CHECKRIDE GRADES OF TEST STUDENTS IN THE UH-1

Student Number	Training Time	Checkride Time	Total Time	Checkride Grade
1	3:00	2:00	5:00	87
2	3:00	2:45	5:45	88
3	6:15	2:00	8:15	88
4	4:45	2:00	6:45	84
5[a]	6:15	3:15	9:30	70
6	5:00	2:00	7:00	85
7	6:45	2:00	8:45	84
8	3:00	1:30	4:30	91
9	3:00	2:00	5:00	83
10	4:00	2:00	6:00	82
11	3:30	2:00	5:30	85
12	3:45	2:00	5:45	80
13	3:30	2:45	6:15	83
14	5:30	3:00	8:30	78
15	3:15	1:45	5:00	74
16	2:45	3:00	5:45	70
Mean	4:12	2:15	6:27	82.0
S. D.	1:21	:30	1:31	6.2

[a]Student 5 did not pass the checkride in the aircraft the first time it was administered. His performance was satisfactory on a subsequent recheck. See the text for comments about this student.

The aircraft time required for this transition training ranged from 2:45 to 6:45. The mean-time was 4:12. It should be noted that a portion of the range of training times was attributed to the IPs' judgment that some students needed more aircraft familiarization than did others. Some of the range, however, was a function of difficulties experienced in the scheduling of instrument equipped aircraft and qualified Army instrument examiners. The latter was a particular problem, since the timing of this test conflicted with the scheduling of these personnel for other duties. In fact, it was found necessary to have three of the aircraft checkrides administered by qualified instrument examiners assigned to the test as IPs instead of using exclusively independent evaluator personnel. In no case, however, did the assigned examiners check their own students.

The aircraft checkride times and grades also are indicated in table 2. It should be noted that one trainee failed to pass the inflight checkride on his first attempt. Unknown to test personnel at the time, this trainee had learned of the death of his mother the evening before the checkride and was awaiting a flight home when he took the checkride. It can be argued that he should not have been allowed to attempt a checkride under those circumstances. Upon returning from emergency leave, he was given one additional familiarization flight and then successfully completed the required checkride. This additional time is included in table 2.

The total calendar time required for the conduct of the experimental training in the SFTS and the familiarization flights and instrument checkrides in the aircraft for the experimental trainees was seven to eight weeks, excluding the one individual whose recheck was delayed by emergency leave. The conventional schedule programs twelve weeks for the Instrument Phase of Training.

DISCUSSION

The fact that SFTS training transfers to the aircraft should surprise no one. It is a high fidelity simulator of the training aircraft. Airline experience transitioning pilots to the 747 and other aircraft has shown that such equipment can provide effective training.

It has been said, however, that the airlines have been able to use simulators effectively because their pilot population is so sophisticated; that these commercial pilots already know all there is to know about flying, and it is just a matter of teaching them to operate a new item of equipment. Since the military undergraduate aviator is not so well qualified, his training must be conducted in the air, or so the reasoning would go.

The study reported here provides evidence that simulators can be used as effectively with undergraduate Army trainees as with highly experienced commercial pilots. In fact, so far as the Instrument Phase of Army undergraduate training is concerned, the training described here was significantly more effective than that conventionally conducted by the Army. The aircraft time was much less, approximately 6:30 hours altogether, for the test group versus 60 hours for the conventional trainees, and the total aircraft and simulator or training device time also was less, approximately 49 hours for the test group (including two checkrides) versus 86 programed hours for the conventional trainees. Also, calendar time was only 8 weeks, versus 12 weeks for the conventional program.

Certainly, the unique design-for-training features of the SFTS contributed to the transfer of training reported here. It should be obvious, however, that the manner in which the device was used contributed to these results perhaps as much as the equipment itself. Undoubtedly, had any existing synthetic training program been used, much of the potential effectiveness of the SFTS would have been lost. An appropriately designed training device can make transfer of training possible, but device design alone does not assure effective training.

The training was conducted on a proficiency basis. Thus, the amount of time required by each trainee to reach criterion performance varied considerably in both the SFTS and the aircraft. It might be assumed that the range of times reported in tables 1 and 2 reflect the times required to bring all students to essentially the same skill level. To an extent, such an assumption is supported by the evidence that more training time did not result in higher checkride grades. The product moment correlation coefficient between training time in the SFTS and SFTS checkride grade is .04, and the corresponding correlation between familiarization time in the aircraft and aircraft checkride grade is -.09.

It is the opinion of the writer, however, that a large part of the range in times should be attributed to differences in the instructing skills exhibited during the test by the IPs involved. Some of the IPs were more proficient in their administration of the training program developed for this test than were others. It is believed that more efficiency can be obtained in subsequent administration of SFTS training with a resulting reduction in the amount of training time required by the less proficient IPs and in the range of training time required.

Earlier in this paper, mention was made of principle features of the training program employed in this study. An additional feature should be added: throughout training, emphasis was placed upon training to stated behavioral objectives, and checks were made almost constantly to minimize inefficiencies resulting from extensive and unnecessary training beyond those behavioral objectives. The entire training program was criterion performance oriented. Conventional training activities, such as "attitude instrument flying" were included in the program only if they were found necessary to the attainment of the required behavioral objectives. In fact, the program is so unconventional that considerable doubt was expressed by experienced aviators concerning its workability. Their doubt has been resolved by the results obtained. The graduates of the SFTS test training program are indistinguishable from their conventionally trained fellow-students so far as measurable instrument flight proficiency is concerned. Only their log books show the difference.

It is clear that military pilot training organizations can make much more extensive use of aircraft simulators in their undergraduate pilot training programs. In fact, with properly designed equipment and training programs, much of the training now conducted in aircraft could be conducted more efficiently on the ground. With existing simulation and training technology, the conduct of 50% of present Army, Navy, and Air Force undergraduate pilot training on the ground might be a modest goal. Within a few years, I believe we will be able to raise that goal to somewhere in excess of 75%. But not if we sit back and say that the only way to learn to fly is to fly.

EFFECTS OF TRAINING SITUATION ANALYSIS ON TRAINER DESIGN

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One of the major branches of military training is maintenance training. In formal schools for aircraft maintenance training it is seldom practical to train personnel in flight line and hanger procedures on line aircraft. To aid in providing these skills, many training devices are employed. These devices each simulate portions of the real maintenance environment the student will encounter in his future work.

The form in which the maintenance task is simulated depends upon the particular training situation or the "use requirements" of the trainer in supporting the overall training course. The training situation therefore determines the general design of the device. Trainers may take many forms, from elaborate mock-ups of major portions of the airframe or its electronic systems, to a simple practice stand where a student can perform a maintenance task until the skills become automatic.

Ideally, flight-line and hangar maintenance training would take place in a real environment utilizing the aircraft, tools, test equipment, and procedures the maintenance man would encounter in actual practice. Unfortunately this is impractical in formal schools where numbers of students in many different specialities must be trained simultaneously and in a short training cycle. In the crowded confines of the aircraft, only one or two students at a time can work on any one operation. The maintenance tasks of the various specialities to be trained either conflict with each other or cannot be performed safely together. Additionally, many operations simply cannot be performed safely until the student has previously practiced and understood the principles. Since the aircraft is not an effective training tool for formal maintenance schoc other types of training devices are needed to expedite and enhance the training program.

A typical formal training program may be divided into two major parts; the lecture phase and the lab phase. The lecture phase provides first a general understanding of the principles involved, and then the how-to-do-it details. The lab phase of training follows much the same pattern of "principles" followed by "applications". The training situation, however, has now moved from the large group, motivated and force-fed by the instructor, to the individual or small group in a self-learning situation, where the principles and the how-to-do-it logic and skills are made their very own.

Training devices may be used effectively in both the lecture and the lab phases of the program. They can assist by adding a visual and tactile focus to the points of the lecture or by illustrating the principles presented. Training devices may be exceptionally useful in the lab phase of training in providing a place to practice how-to-do-it problem solving with tactile, visual, and audio reinforcement of the training.

Visual and audio aids of many kinds are available to assist the training program: films and tapes, projected or permanent graphics, programmed instruction devices, and plain old fashioned texts. In fact, the single most valuable aid is the aircraft maintenance manual itself. Each of these classes of aids can be of great value to the training program, and it would be very interesting to explore the effects of changing training situations on the design and use of these aids. However, none of these aids provide the student with tactile reinforcement of the lecture or with the opportunity to practice procedures until lecture theories become personal skills.

Student-operated training devices which simulate portions of the aircraft maintenance environment do provide this combination of theory reinforcement and tactile practice. It is our purpose here to explore the effects of changing training situations on the design of these devices for the Naval Air Maintenance Training Detachments (NAMTRADETS) and the Air Force Field Training Program.

The maintenance trainer of 20 years ago was aimed at the training-in-grade of already skilled personnel to maintain a basically familiar system, such as hydraulics, on a new model aircraft. Since the people were already skilled in their speciality, training cycles were short and aimed primarily at understanding the functions of the overall system rather than skills such as rigging or installing a hydraulic cylinder. As a result, maintenance trainers tended to emphasize overall system operation, relationships, or principles. These functions are best shown and taught graphically. The typical hydraulic system trainer of the period was an animated schematic on which system relationships could be demonstrated, isolated, or repeated at will, emphasizing the point of the lecture. Manual skills training and fault isolation practice using real hardware were not requirements for the maintenance trainer, and consequently, were seldom provided.

As the average time in service of the maintenance personnel decreased over the past 20 years, and the number of operating squadrons increased, the training load increased correspondingly. The operating squadrons were faced with increased training requirements to upgrade personnel, as well as transition training for improved models of aircraft. From this evolved the Air Force's Field Training Detachment (FTD), as well as an enhanced Naval Air Maintenance Training Group program.

The FTD's and NAMTRADETS, groups of full-time instructors equipped with maintenance trainers, are assigned to a base for a long period of time to assist operating squadrons with maintenance training. Instead of "transition-training" skilled personnel in grade, emphasis is placed on upgrading the skill level of the personnel. As a result, the design requirements for maintenance trainers changed to meet the increased emphasis on skills training. The animated schematic style trainer was typically replaced by an operating hardware mock-up of the system in the airplane, and graphic aids took over the task of illustrating system theory and function during the lecture phase of instruction. The maintenance trainer, therefore, became the primary training tool in the lab phase of instruction. The requirements for a typical maintenance trainer became: Provide familiarity with the equipment as it is installed in the aircraft; provide applied practice in maintenance operations, parts replacements, rigging, adjustment, and safety practices; and provide trouble shooting and fault isolation practice.

We have examined the general role of training devices in the maintenance training program today and the resulting requirements the trainers must fulfill. Let us now look in more detail at the process whereby the maintenance trainer is fitted to that role.

Before any requirement exists to design a trainer, the need for the trainer must be established. Aircraft system maintenance procedures are analyzed to define the skills needed by the maintenance personnel. Training requirements to provide these skills are defined and reviewed to determine which kinds of aids will best promote these skills. If a maintenance trainer is needed, the general nature of the trainer is determined. For example, would an operational mock-up, a static display, or an animated display best fulfill the requirements?

The next step is establishment of detail design requirements. If an operational trainer is to be provided, the requirements for operating the system in the classroom, isolated from the rest of the aircraft systems, must be determined. What input signals or output displays must be provided synthetically to allow a navigation system to function normally? What safety hazards exist around a radar system in a classroom? What security problems will an operating counter-measures trainer present?

Some general considerations in setting detail design requirements are:

- Accessibility to students.
- Maximizing the number of student training stations.
- Generating student enthusiasm.

- Good transfer of training to the aircraft environment.
- Transportability.
- A short engineering and delivery cycle.

When the detail design requirements have been fully developed, potential solutions to these requirements must be evaluated and the general configuration established. The proposed configuration is then submitted to the customer for approval.

With customer approval to this point, detail design or engineering can now begin. Designing is basically an iterative process. The general design is subdivided into functional components, and again requirements are established with alternative solutions sought and evaluated. Eventually a preferred design will be selected for each of the components. This process proceeds in ever greater detail until the design is complete.

Consider the effect a change in training requirements can have upon maintenance trainer design using two different training situations applied to two versions of RF-4 camera system trainers. The RF-4C camera trainer, shown in Figure 1, was designed to meet mobile training detachment requirements for "transition-training" personnel already experienced in their specialty. It consisted of an operational mock-up of the camera installations on two open panels. The viewfinder, cockpit equipment, and camera parameter control unit were mounted on an electronic workbench. The trainer featured transportability, easy access for system troubleshooting and maintenance practice, and numerous training stations. The trainer did not attempt to present realistically the conditions surrounding the performance of maintenance tasks in the aircraft. That form of "finger-dexterity" was not a requirement for the experienced personnel being trained.

The RF-4B camera trainer, shown in Figure 2, was designed for a permanent school to provide training for both skilled personnel transitioning to the new aircraft, and for personnel fresh from basic school who had yet to work on their first aircraft. In this case, transportability was not a prime requirement: thus the panels could be heavier and larger. Training in camera installation and removal, the use of camera hoisting equipment, camera door rigging, and system trouble-shooting was required. To provide these mechanical skills, as well as trouble shooting practice, a complete operational camera installation within the confines of a mock-up of the interior of the aircraft nose was mounted on one panel. The viewfinder and aft cockpit controls were mounted on an electronic work bench. Within the confines of the nose, all installations, clearances, and encumbrances provided realistic conditions in which to practice the desired skills under flight-line conditions. Since the trainer was designed for the Marines, some thought was given to adding rain and mud for utmost realism. After some consideration, this requirement was waived. This greater emphasis on "finger-dexterity" and realism of practice had a price. Easy transportability was sacrificed, the number of available student training stations was reduced, and ease of access for both lecturing and practice was lost.

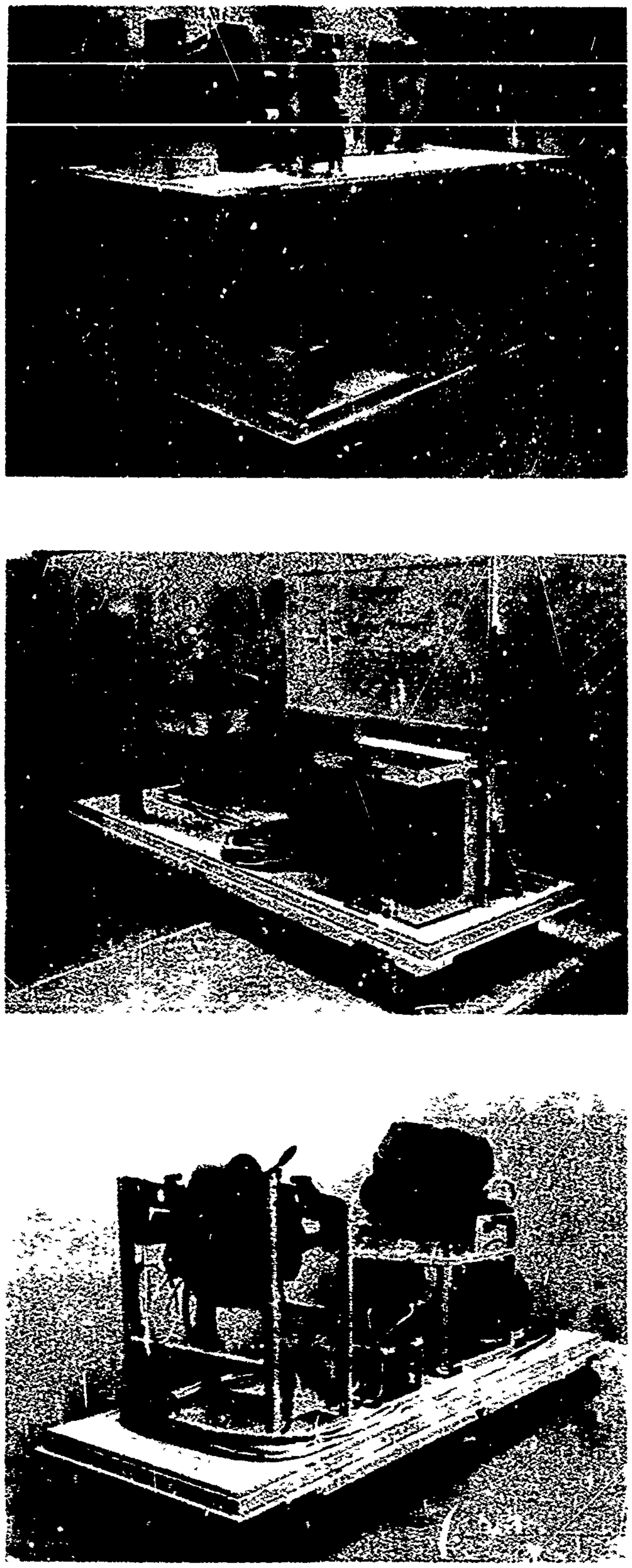
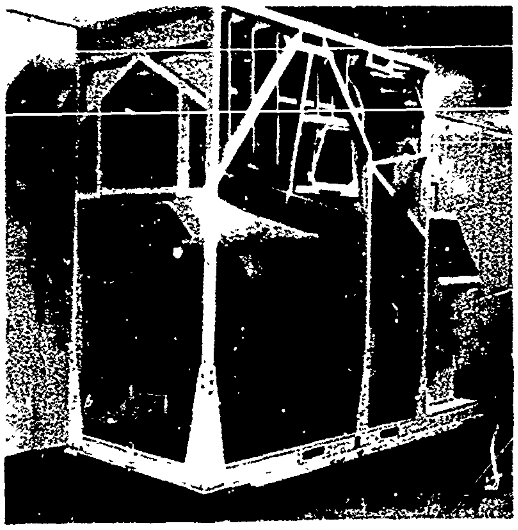


Figure 1. RF-4C Camera Trainer



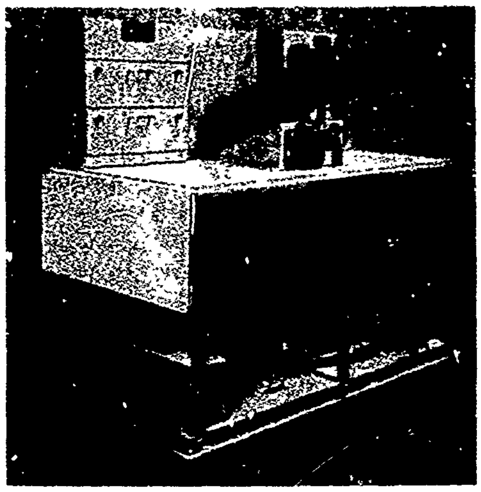


Figure 2. RF-4B Camera Trainer

In the above example, the final skills requirements of the maintenance people were the same for both schools. The RF-4B school expected to receive a greater percentage of students with little experience in maintenance of photo systems in aircraft and consequently additional requirements for applied skills training had to be satisfied. As a result, it became a design requirement to provide a greater degree of realism in simulating the aircraft maintenance environment in the RF-4B camera trainer. The changing training situation was reflected in the change in design described in the example.

In summary, economics of use require that formal schools use training devices to simulate the aircraft maintenance environment rather than use the aircraft itself. Individual trainers, of necessity, simulate only selected portions of that maintenance environment. Because of the economics of use, each trainer is a compromise satisfying only the most urgent training requirements which cannot be more economically fulfilled in some other way. Careful analysis of the projected training situation is required to establish and evaluate the training requirements to be met by the training device. Only with careful training situation analysis can the design of the trainer be guided to meet the needs of the training program and provide the customer with the best possible training capability for the money spent.

QUANTITATIVE TASK ANALYSIS AND THE PREDICTION OF TRAINING DEVICE EFFECTIVENESS

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Because of the enormous costs involved in the design and development of a complex training device, one can ill afford to adopt a "wait-and-see" attitude about the effectiveness of training which it provides. The primary problem confronting individuals responsible for military training, therefore, is how to plan for, design, and develop a training device from the very start, which will prove to be effective for a particular set of training objectives. But, given the requirements for training, how can one forecast or estimate how effective any specific design will be? For example, as designed will the device facilitate or inhibit ease of instructor operation (i.e., presentation of problem materials, monitoring and evaluation of student performance, provision of feedback)? Similarly, from the student point of view, will the design lead to rapid acquisition of skills and their positive transfer to the operational setting?

If answers to these types of questions could be given early in the design and development process, then a basis would exist for comparing and contrasting the "relative goodness" of alternative designs prior to actual development. By systematically evaluating alternative designs in terms of predicted training effectiveness, we might better be able to insure that the design finally adopted is better than other designs which may have been under consideration. This, after all, is the basic point. It would be desirable to have some early indication that the adopted design will provide superior training, relative to competing designs.

In the 25 years since World War II, few other training problems have received as much attention. The problem has come under repeated attack and has been approached from a number of different theoretical positions. Various methods have been conceived to help determine what should be trained and how training should be accomplished. Many of these approaches have shared the assumption that operational tasks possess certain critical characteristics which have specific implications for the design and utilization of training devices. It was hoped that this information, together with estimates of cost, would lead to training decisions which insured maximum returns for each training dollar invested. In spite of several efforts in this direction, however, the problem of prescribing the design of a training device, or of predicting its effectiveness, remains unsolved.

THE EARLY YEARS--INTUITING THE SOLUTION

Historically, gross inadequacies in the design of training devices were often eliminated on the basis of shrewd guesswork. In the earliest approaches, design decisions were made by subject-matter specialists, who drew on experience and common sense, to solve training design problems. As a result, they often were able to make fairly sound decisions about the design of training aids and equipment, student and instructor stations, and other aspects of the training situation which might facilitate the learning experience. However, these early practitioners were artisans. Because of their experience, they were able to translate certain types of information about the job to be performed into requirements for training. As is true of all artists, however, they differed in terms of their conceptualization of and their approach to the training problems which faced them. As a result, some were highly successful in making sound training decisions. Others were not. Furthermore, be-

cause of the informal and implicit nature of their methods, it was difficult to train others in their use. But the major disadvantage of this approach lay in the difficulty of evaluating the proposed training solution prior to its adoption. Predictions as to the effectiveness of training were scarcely better than opinion.

QUALITATIVE TASK ANALYSIS--A CERTAIN AMOUNT OF NAME CALLING

Because of the difficulties inherent in these individualistic methods, attention was focused upon the development of more formal and programmatic approaches. The results of these efforts were a number of job descriptive and task analytic procedures. Using these approaches, it became possible to describe jobs in terms of their major task components, and then to describe these components in terms of underlying task elements and activities. Description proceeded systematically through several levels. The earliest of these procedures (e.g., Miller, 1953; Miller & Van Cott, 1955) were designed to help specify those aspects of an operational task which should be considered as basic items of content in a training program. More recent efforts (e.g., Chenzoff & Folley, 1965), while retaining an interest in specifying the appropriate content of training, have also attempted to prescribe the manner in which training should be accomplished. Among the more advanced of these techniques is the Training Analysis Procedure (TAP) currently in use at the Naval Training Device Center. As described in the Fourth Annual Conference (Middleton, 1969), TAP is designed to aid in developing device requirements and translating these into functional characteristics of training hardware.

Other investigators have attempted to formalize training decisions by developing task classification systems having implications for training. These taxonomists shared the belief that basically different types of tasks did indeed exist. Given this premise, a logical step was to collect, sort, and catalogue tasks, casting them into their appropriate classes or families. For each identifiable class of tasks there might exist an unique or optimally effective set of training procedures. As a consequence of this thinking there have been several attempts to classify tasks and to specify for each class those training techniques which seem most appropriate (e.g., Willis & Peterson, 1961; Stolurow, 1964; Miller, 1969).

Many of the analytic and taxonomic methodologies developed to date have had their own particular problems. Most, however, have shared one weakness. They have become too dependent upon a process of name calling or labelling. A certain amount of name calling, of course, is inevitable, and in and of itself is harmless enough. But when a specific training decision may rest upon the label given a particular task element, and when we often can't agree on the label to apply (e.g., decision making, problem solving, inductive reasoning), then there is cause for concern. At this point the objectivity and reliability with which tasks can be described and analyzed are in doubt.

Such is the case with many of the classical task-analytic approaches. They have provided for the description of tasks in behavioral or functional terms (e.g., the behavioral taxonomy of Berliner, Angell, & Shearer, 1964; the functional descriptors employed by Gagne, 1962; and by Miller, 1966). These terms have been found difficult to apply unambiguously. This difficulty, coupled with the fact that the terms in use permit only qualitative distinctions to be drawn among different tasks, limits the utility of these approaches. While they may help to determine the basic content of training,

and although they may even provide general guidelines about how training should be conducted, these approaches will not aid in the prediction of training effectiveness.

QUANTITATIVE TASK ANALYSIS--PIGEON-HOLDING BY THE NUMBERS

In order to augment these conventional task-analytic procedures, therefore, the Naval Training Device Center has been seeking alternative ways of using information about the features of a training device and about the characteristics of the tasks performed within that device. Desired is a more reliable and objective method of task description which might be used to forecast training effectiveness. Underlying this effort there have been two issues of primary importance. First, would measures of training effectiveness (i.e., rate of skill acquisition, level of transfer) vary in some predictable manner as features of a training device were manipulated? Unless there was a relationship between these two sets of variables, prediction of effectiveness would not be feasible. Second, and even more basically, would it be possible to describe the critical features of a device reliably and along a number of quantitative dimensions? Unless such description were possible, there would be no way of investigating the relationship of interest.

To resolve these issues a research program was initiated by the Naval Training Device Center and the American Institutes for Research (AIR) which had three objectives. These involved: (a) Exploring ways of reliably describing features of trainee or instructor stations in quantitative terms; (b) determining whether the quantitative descriptors could be used to describe fairly complex devices; and (c) developing statistical methods for relating the quantitative descriptors to variations in device effectiveness.

In pursuit of these objectives, a variety of computer-driven and tape-based sonar training devices were examined, in order to identify features, which could be quantified. As a result of these efforts, a number of quantitative task-descriptive indices were assembled. These indices, developed by AIR, represented critical dimensions of the stimulus, response, and procedural aspects of trainee and instructor stations. Critical dimensions were those which, if manipulated, would be expected to affect level of (instructor) proficiency, rate of skill acquisition, or degree of transfer. Included among the indices were a variety of rating scales relating to such dimensions as work load, precision of responses, and response rate. Other indices were based on metrics such as the Display Evaluation Index (DEI) developed by Siegel and his co-workers (Siegel, Miehle, & Federman, 1963) and the several panel layout metrics developed by Fowler and his associates (Fowler, Williams, Fowler, & Young, 1968). The DEI is basically a measure of the effectiveness with which information flows from displays, via the operator, to corresponding controls. The panel-layout indices represent the extent to which general human-engineering principles have been applied to the design of hardware.

Application of the indices to four trainee tasks; (i.e., set-up, detection, localization, and classification) as represented in a variety of different sonar training devices, was attempted. This exercise demonstrated that most if not all of the indices could be used reliably to scale the extent and manner in which the trainee tasks differ across devices. By extension, therefore, the indices can be used to describe reliably and quantitatively how competing designs of the same device differ.

Can such quantitative information be related to measures of training effectiveness? In the final analysis, there is no way of specifying a priori which indices will bear a relationship to measures of performance, learning, or transfer. In order to explore the relationship between variations in design parameters and training effectiveness criteria, additional research is required.

Such research has been undertaken by AIR for NAVTRADEVCEN and is currently in progress. Training-effectiveness data are being collected both in the field and in the laboratory to provide criteria for regression analysis. The laboratory data are being obtained with the aid of a synthetic "trainer" which is an abstraction of the many sonar devices examined earlier in our research for NAVTRADEVCEN. The field data are being obtained through questionnaires, given to instructors and to trainee personnel. These questionnaires are designed to elicit estimates of the effectiveness of specific sonar trainers under standardized conditions. Use of the questionnaire, as opposed to more explicit performance evaluation, is being employed because of the well-known difficulties of accessing field equipment directly. Based on these field and laboratory data, regression equations will be developed. Such equations, if successfully validated, would permit the effectiveness of a given design to be predicted from knowledge of index values descriptive of that design. That is, we could then "pigeon-hole" by the numbers.

The trend away from purely qualitative task analysis procedures toward more quantitative techniques will result in improved training solutions. Such techniques offer promise in assuring the effectiveness of a training device earlier in the design process. Until these techniques are formally developed, predictions of trainee or instructor proficiency on particular trainer configurations will continue to be as much art as science.

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SESSION II

Tuesday, 15 February 1972

Chairman: Mr. George Derderian
Head, Physical Sciences Laboratory
Naval Training Device Center

A MODIFIED MODEL FOR VISUAL DETECTION*

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AND
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The requirement to predict the human ability to visually search and detect has occurred in a wide variety of problem areas. At Cornell Aeronautical Laboratory, Inc. (CAL) specific areas involved both ground-to-air and air-to-air search for aircraft against a sky background, and the search for small targets presented in simulator displays.

Models to predict human visual performance have been available for some time. The purpose of our paper is twofold: (1) To present a modified version of a widely known visual detection model and; (2) to compare the predictive capability of the modified version with both the original model and results of field tests involving ground-to-air search for aircraft.

THE MODEL

The first comprehensive work on visual search of a homogeneous background was done by Craik in the early 1940's. The results of his study, along with those of other studies to account for performance degradation due to atmospheric haze and to describe the detection process in a probabilistic fashion, have been organized by Koopman (1946) into a very workable and convenient model. Although the model is widely known, it is necessary to summarize its main features for this discussion:

1. In free search the eye does not scan continuously, but jumps from point to point. The eye remains fixed at each point for approximately 1/3 second for search in a homogeneous or unstructured background although longer fixation or "glimpse" times can be anticipated for search in complex backgrounds. The point in the visual field conjugate to the center of the fovea (retinal region of maximum acuity) is known as the point of fixation.
2. Target contrast (C) is defined as the average luminance difference between the target and its background, divided by the background luminance. The threshold contrast of a target (C_t) is the contrast at which the detection probability for a single glimpse assumes some nominal value. Koopman has employed a probability value of 0.57, and has expressed the threshold contrast for a single glimpse by:

$$C_t = \begin{cases} k_1\theta^{k_2} + \dfrac{k_3\theta^{k_4}}{\alpha_2} & (\theta \geq \theta_f) \\ k_1\theta_f^{k_2} + \dfrac{k_3\theta_f^{k_4}}{\alpha^2} & (\theta < \theta_f) \end{cases} \qquad (1)$$

---

* This work was sponsored by the United States Air Force under contract number F33615-68-C-1319.

where: θ = angle subtended at the eye (in degrees) between the point of fixation and the target ($\theta \doteq 90°$)

θ_f = half-angle of fovea ($\theta_f = 0.8°$)

α = average angular diameter (minutes of arc) of the target subtended at the eye

$k_1 = 0.0175$ $\quad k_3 = 0.19$

$k_2 = 0.5$ $\quad k_4 = 1.0$

3. The probability of detection (g) during a single glimpse depends only on the ratio of target contrast to the threshold contrast of the eye (C/C_t) and is given in figure 1.

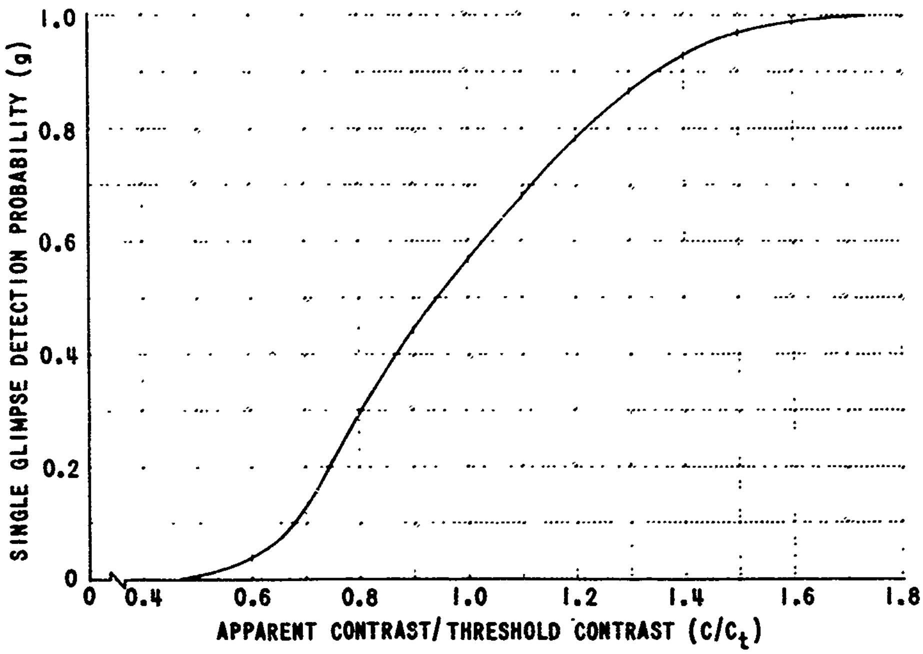


Figure 1. Glimpse Probability of Detection "g" vs Apparent Contrast/Threshold Contrast, C/C_t

4. Contrast is degraded by the atmosphere. Due to scattering by haze, the apparent target contrast (contrast seen by the observer) is reduced according to path length and haze concentration. The haze concentration is determined from the meteorological range, a mathematically precise measure designed to correlate with the general ability of the human to see through the atmosphere. The relation between the the contrast apparent to an observer (C) and the inherent contrast (C_o) was given by Middleton (1968) for horizontal view paths:

$$C = C_o e^{-\sigma R} = C_o e^{-\frac{(\ln 50)R}{V}} \tag{2}$$

where: σ = optical attenuation coefficient of atmosphere (meters^{-1})

R = separation distance between observer and target (meters)

V = meteorological range (meters)

An account of atmospheric degradation for slant paths requires a much more complex mathematical description. Since such a generalization is peripheral to the theme of our paper, we shall confine our discussion to view paths that are essentially horizontal.

5. The search procedure consists of "continuously glimpsing" (one glimpse after another) at spatially random points within the designated search field. The probability of detecting the target during a single glimpse (instantaneous probability) is given by simply averaging "g" over the search field:

$$\bar{g} = \frac{2\pi}{M^2\Omega}\int_0^{\theta_0} g(\theta)\sin\theta\, d\theta \tag{3}$$

where: $\bar{g}$ = average detection probability for single glimpse

Ω = solid angle of search field

θ_0 = one-half the apparent field of view of optics (e.g. 90° unaided eye, 28° binoculars)

M = linear magnification of optics

It should be noted that in addition to the search field Ω, an account of masking by the field stop is also included.

MODEL MODIFICATION

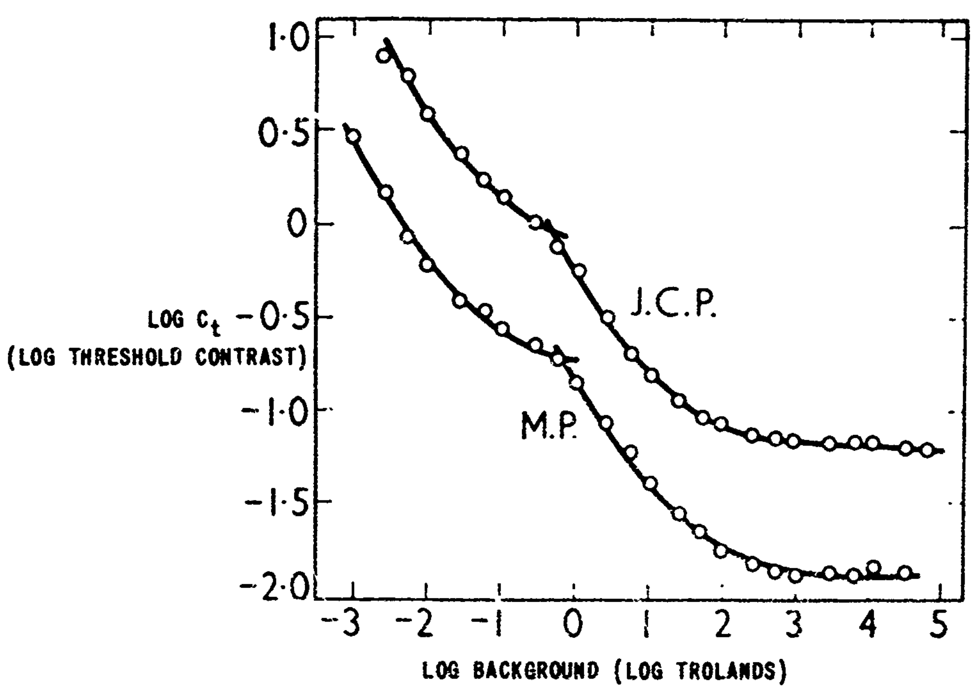
The model described above has undergone two modifications during its use at CAL. First, the mathematical expression relating threshold contrast, target size, and position in the visual field has been adjusted to agree with specific data subsequently published in the literature. The motivation for this was our feeling for some time that the detection ranges predicted by the model were on the high side.

Second, the actual distributions of the peripheral angle (angle between the aircraft and the visual fixation point subtended at the observer) have been generated for various postulated geometric configurations involving the search field, target location and random search distribution. These distributions are used as a base for computing the average glimpse detection probability $\bar{g}$. (Although only specific distributions were employed in our study, any configuration can be handled by generation of its corresponding distribution.) Prior to the use of these distributions, the integration involved in determining $\bar{g}$ assumed the significant region of the visual field was completely contained within the search field, an approximation that allowed the simple integration procedure indicated by Equation (3).

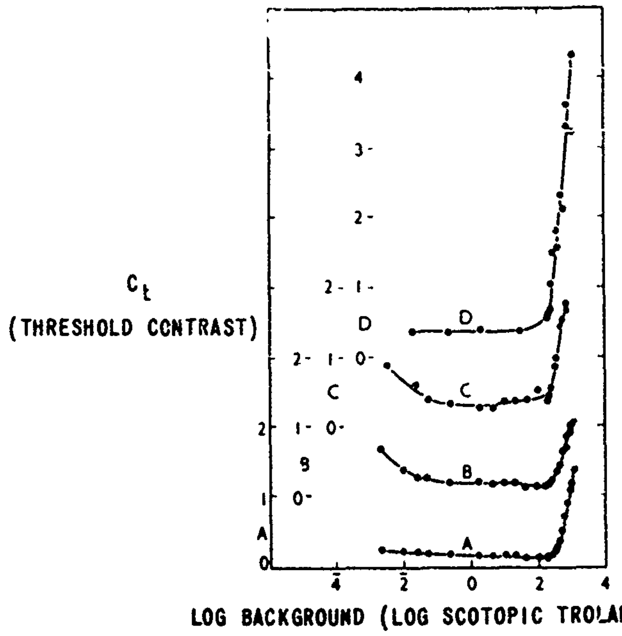
*For our application, Weber's Law states that the brightness difference at threshold is proportional to background brightness.

The threshold contrast expression (Equation (1)) was adjusted to fit threshold data published by Sloan (1961). Sloan has measured, for monocular viewing, "just perceptable differences" of small stimuli against a uniform background. She presented oval stimuli of uniform luminance for durations of approximately one second. The range in angular subtense (average diameter) at the eye was from 3 min of arc to 100 min. The "oval" nature of the stimuli resulted from optical distortion in the apparatus, not design, but the ratio of largest to smallest dimension was always less than 2:1. The thresholds were taken at a background luminance of 3.16 mL (10 nit) and include the dependence on position in the visual field. Only stimuli brighter than the background were used.

Initially there were two points of concern regarding the use of the Sloan data with the background level of 10 nit since this level is two to three orders of magnitude smaller than the daytime sky. The first relates to the validity of Weber's Law* which provides that background and stimulus brightness affect target detection only through contrast. Pirenne (1962) clearly illustrates (figure 2a) the validity of the law for retinal illumination levels above 1000 trolands. However, Sloan's background of 10 nit results (via adaptation) in an eye pupil diameter of 4 mm (LeGrand - 1957) thus yielding a retinal illumination of only 125 trolands. It is seen from figure 2a that the departure from Weber's Law is very small at this level and one can anticipate that the error arising from the departure may be negligible compared to the correction obtained by employing the Sloan data.



a. Threshold Dependence on Background for Two Observers (J.C.P., M.P.) (The Points for M.P. have been lowered 0.5 Log Units)



b. Threshold Dependence of Rods Only on Background
For 4 Observers (A,B,C,D)

Figure 2. Threshold Dependence on Background Luminance (After Pirenne - 1962) (Reproduced through permission of Copyright Holder, Academic Press, 1962)

The second point of concern was regarding the role of the rods in the detection process. The spectral distribution of Sloan's background and stimulus was essentially that of Illuminent A (Tungsten) and therefore the illuminance of 125 trolands converts to 70 scotopic trolands when adjusting for the spectral response between cones and rods. It is seen (figure 2b) that this falls in the upper part of a sensitivity range for which Weber's Law is valid for the rods. Also it is a range of maximum contrast sensitivity (minimum contrast threshold) of the rods which does not correspond at all to sky background at which rod saturation is achieved. Although this difference exists, it is not believed to be important since, as indicated in figure (2a), the transition from cones to rods as the determinant of threshold occurs slightly below 1 troland and Sloan's value of 125 trolands provides a safety factor of two orders of magnitude.

There are three points that should be made regarding Equation (1). The first relates to the rotational symmetry of C_t about the fixation point. Equation (1) provides that C_t does not depend on both angular coordinates of the stimulus in the visual field, but only on the difference angle between the stimulus and the fixation point. Although Sloan's data indicate an asymmetry (primarily in the horizontal meridian) it is not large, and is somewhat averaged out for an observer using both eyes. Second, no statistical definition of threshold contrast was used by Sloan, so we assume her data to lie in the region of 50% detection probability, and therefore they were arbitrarily equated to C_t of Equation (1). Should the assumption be proved invalid the abscissa of the single glimpse probability curve (Figure (1)) can be scaled accordingly. The third point relates to the dependence of threshold contrast on stimulus size. Sloan states that the data are usually fitted by an equation of the form:

$$C_t = \beta_2 (\alpha^2)^{-\beta_1} \tag{4}$$

where β_1 and β_2 depend only on position in the visual field. Of the two possibilities for fitting a model to Sloan's data (Equations 1 or 4) Equation (1) was used since it is more reasonable asymptotically for both small and large α. The difficulty with Equation (4) can be understood by considering the asymptotic constraints on β_1. As α becomes small, point stimuli are approached and C_t must vary as α^{-2} thereby requiring $\beta_1 = 1$. For large α, we expect C_t to be relatively insensitive to α thereby indicating a β_1 close to zero. Since β_1 does not depend on α, Equation (4) cannot hold over such a large α range, and we shall not consider it further.

The data selected for fitting Equation (1) is shown in figure (3a). This data was fitted by varying $k_1 \ldots k_4$ of Equation (1) to minimize a square error (ϵ). It was decided to minimize in log space without a weighting function. That is:

$$\epsilon = \sum_{\substack{data\\points\\(\theta \neq 0)}} \left(\eta_{d.p.} - \eta_{Eq.(1)}\right)^2 \tag{5}$$

where η is the log of the threshold brightness difference in units of log μL. The value of $\eta_{Eq.(1)}$ is related to C_t of Equation (1) by:

$$\eta = \log C_t + 3.5 \tag{6}$$

The term "3.5" in Equation (6) is simply the log of Sloans background luminance in logμL.

The square error (ϵ) of Equation (5) was minimized using a direct search procedure which resulted in the following new values:

$$\begin{aligned} k_1 &= 0.0265 & k_3 &= 0.44 \\ k_2 &= 0.24 & k_4 &= 1.6 \end{aligned} \tag{7}$$

It is the replacement of these k values for those indicated in Equation (1) that comprises the major modification of the visual detection model. Threshold curves (in the ordinate η) are shown in figures (3b) and (3c) for the former and the present values of k respectively. The new values provide a substantially better fit to the data, with the most significant change being a large increase in the threshold for small stimuli in the peripheral region.

PERIPHERAL ANGLE DISTRIBUTIONS

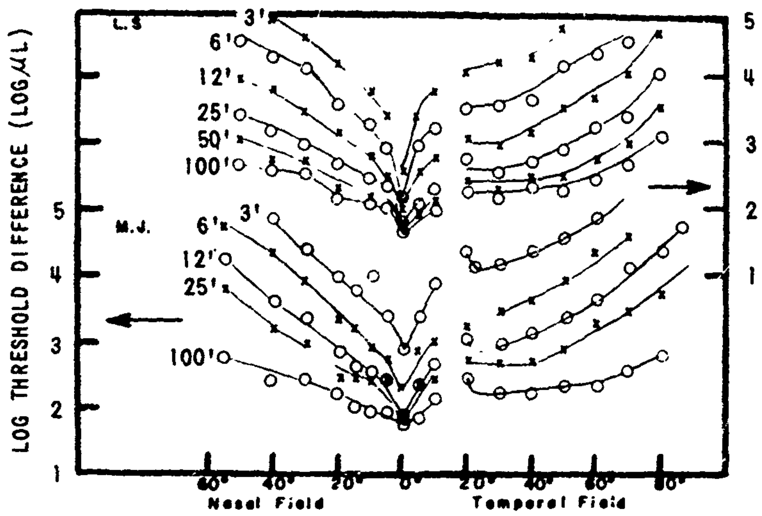
The determination of the single glimpse detection probability (g in figure (1)) requires specification of the threshold contrast C_t which in turn depends on the peripheral angle (θ) in Equation (1). That is, formal elimination of C_t between Equation (1) and figure (1) allows us to write:

$$g = g(\theta) \tag{8}$$

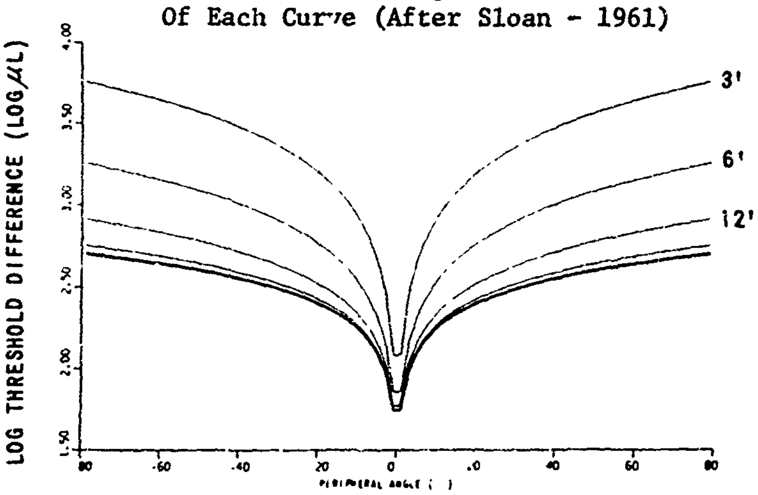
where the arguments C and α have been dropped since our interest here is only with the angle θ. The peripheral angle θ is the angular difference (at any instant) between the stimulus (target) and the visual fixation point subtended at the observers eye. Since it is customary to treat the target and fixation

positions as random variables, the peripheral angle is also a random variable. Thus in order to establish an explicit value of detection probability at any "instant" (single glimpse), it is necessary to specify the target and fixation positions as probability distributions, and compute an expected value ($\bar{g}$) over the search field.

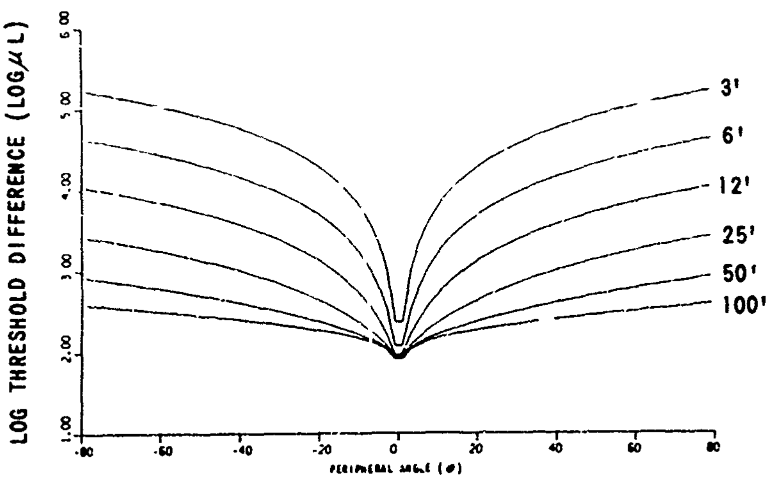
The original model assumes a uniform distribution of target position within the search field. It was further assumed that the region of the visual field surrounding the fixation which is important to detectability in the practical case is small, and therefore the border of the search field can be ignored when carrying out the averaging integral. These two assumptions allow $\bar{g}$ to be written according to Equation (3).



a. Threshold Gradients in the Horizontal Meridian The Size of the Test Object is Shown at the left Of Each Curve (After Sloan - 1961)



b. Threshold Gradients Predicted by Original Model



c. Threshold Gradients Predicted by Modified Model

Figure 3. Comparison of Data and Model Threshold Gradients

With regard to the two assumptions underlying Equation (3), the latter, involving negligible interaction between the visual field and search field border, is easily dropped. With complete generality we can write:

$$\bar{g} = \int_0^{\pi/2} P_e(\theta) g(\theta) d\theta \tag{9}$$

Where $P_e(\theta)$ is the actual probability density of the peripheral angle θ and includes all the information defining the search field, optical magnification and the distributions of target and fixation within the search field. The establishment of distributions (P_e) for the search configurations of interest and the computation of $\bar{g}$ through Equation (9) are, in essence, incorporated in the present model as a replacement for Equation (3).

The use of the distribution $P_e(\theta)$ is somewhat clumsy due to the dependence on optical magnification. That is, a separate distribution would have to be generated for each magnification value desired in order to compute $\bar{g}$. It was found to be convenient to write Equation (9) in terms of the angle (θ') separating the target and corresponding fixation point as it occurs in the actual search field Ω_o. Clearly, the relation between θ and θ' is:

$$\theta = M\theta' \tag{10}$$

Where: θ = peripheral angle within visual field (at eye)

θ' = peripheral angle in real world.

In terms of θ', Equation (9) can be written*:

$$\bar{g} = \int_0^{\pi} P(\theta') g(M\theta') d\theta' \tag{11}$$

*The Upper limit of π in Equation (11) is symbolic. It simply implies the integration is carried out until either P or g becomes zero. It was used to provide validity should the magnification ever be <u>less</u> than unity.

Where $P(\theta')$ is the probability density of the angle θ', and is independent of magnification.

Initially it was attempted to generate $P(\theta')$ distributions assuming the target and fixation distribution were distributed uniformly within the search field and a corresponding equation for the distribution is derived in the appendix. This approach was abandoned since it was too time consuming on the computer. It was decided instead to compute $P(\theta')$ for specific target positions, and the equation for this distribution is also given in the appendix.

Specific distributions were generated again assuming a uniform fixation density within various search fields of interest, and examples of the distribution are shown in figure (4). The fine structure along the tops of these distributions is coherent noise in the form of a moiré pattern resulting from overlapping of the search field border and the discretely sampled coordinate system used in the actual computer calculation of the distributions. The fluctuations are small and can be ignored.

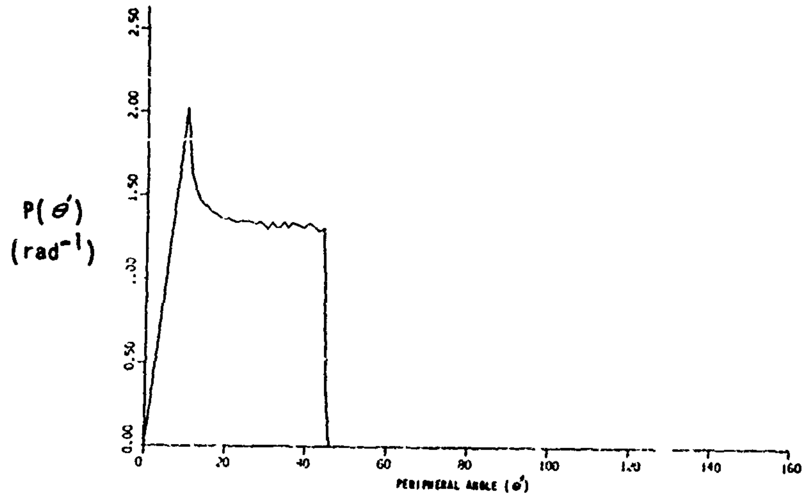
The distributions were punched on cards and are available as data arrays within the computer verison of the present model. Computer test runs indicate only slight differences between the detection probability values resulting from the former and present expressions for $\bar{g}$ (Equations (3) and (11) for the search geometries of interest in the present study. However, other search configurations may result in large differences and for that reason, Equation (11) should be employed.

COMPARISONS OF ORIGINAL MODEL, MODIFIED MODEL, AND FIELD TEST RESULTS

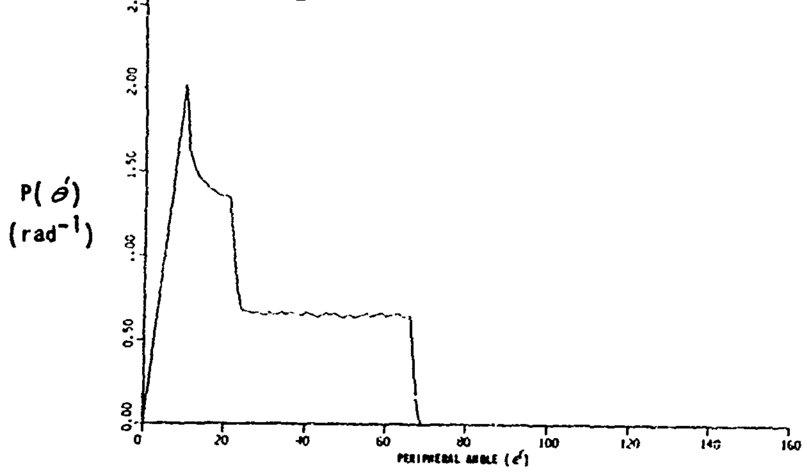
Having made the two model modifications just discussed, the next step was to determine the present model's predictive capability by comparison of the original and modified detection models with experimental results reported in the literature. An attempt at such comparisons quickly revealed the difficulties that are encountered when trying to verify a model with experimental data obtained from tests not designed specifically for verification of the particular model. Usually the experimental data are incomplete in their specification of one or more of the conditions of the experiment which are necessary for model inputs, i.e., contrast, meteorological range, glimpse time, target area, and search field size.

One notable exception is the experimental work reported by E.K. Seyb (1966) in which results are given for detections by the unaided eye from field tests conducted in Germany. The results are plotted in a meteorological visibility-detection range coordinate system, with cumulative probability of detection as a parameter, for the typical parameter values given in table 1. Seyb also mentions that, "as far as meteorological visibility was concerned, the test results of the German field tests were only available in intervals of 2 km." The experimental data were converted for purposes of the present study, to cumulative probability of detection versus range for constant values of meteorological visibility. This form of the data is compared with results obtained from runs of both the original and modified models using as inputs the values given in table 1.

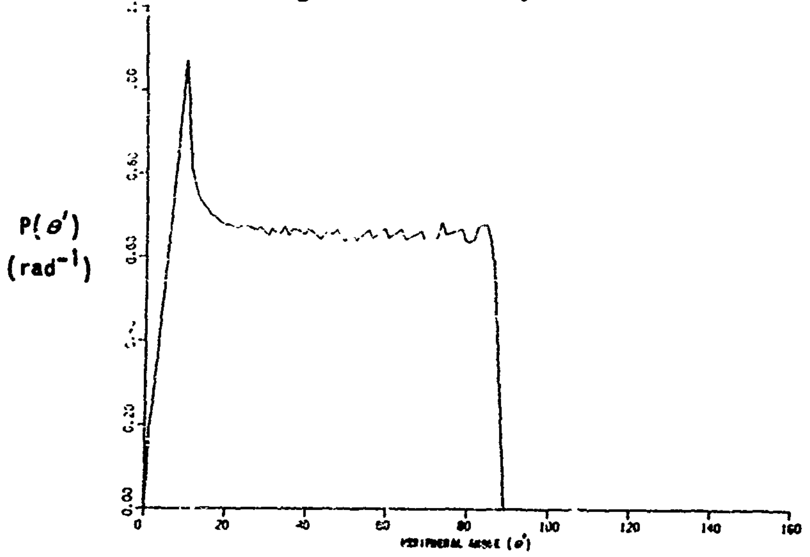
It should be noted that the only reference to aircraft size is through the visible area of 5.5 meters^2. The aircraft was not specified by Seyb, but since the altitude is low, and radial flight paths were employed, the visible area was not varied during the computer runs.



a. Target Centered within Search Field



b. Target Horizontally Offset 23° From Center



c. Target Horizontally Offset to Edge of Search Field

Figure 4. Peripheral Angle Distributions for a Search Field 90° in Azimuth and to 20° Above the Horizon

TABLE 1. FIELD TEST CONDITIONS
(AFTER SEYB - 1966)

Parameters	Mean Values
Velocity	60 m/s
Altitude	0.1 km
Offset	0.0 km
Inherent contrast, C_o	0.93
Glimpse Time	1.5 sec
Visible area	5.5 m^2
Search Field Size	30° Az x 5° El
Meteorological Range	5, 7, 17, 21 km

We should also mention that it was necessary to assume a target position within the 30° x 5° search field in order to generate a peripheral angle distribution for the modified version of the model. A location of 5° Az from the search field center, and 2° El above the horizon was employed.

Figures 5a and 5b compare experimental results with model prediction for meteorological visibilities of 21 and 17 km, respectively. Experimental data points are represented by circles. The theoretical predictions include those made using the original model as well as those obtained using the modified model. It is readily seen that for a given probability of detection, the original model results consistently predict greater ranges of detection than the modified model. Additionally, the modified model predicts the experimental data fairly well. Results for meteorological visibilities of 7 and 5 km are shown in figures 6a and 6b, respectively. Here, again it may be seen that the cumulative curves obtained with the original model lie at greater ranges than those obtained for the modified model. The modified model results, again, lie closer to the experimental data. The larger discrepancy between model and experimental results for the lower meteorological visibilities may be partially a result of the interval of presentation of the data; i.e., test results were available only in intervals of 2 km.

SUMMARY

The primary result of this study has been the modification of an existing visual detection model to provide better agreement with known performance data. Comparisons with field data have shown the modified version to be preferable to the original, since the original predicts a highly optimistic detection performance. Based on these comparisons, we recommend the use of the modified version in problem areas whose conditions are consistent with the model features described above.

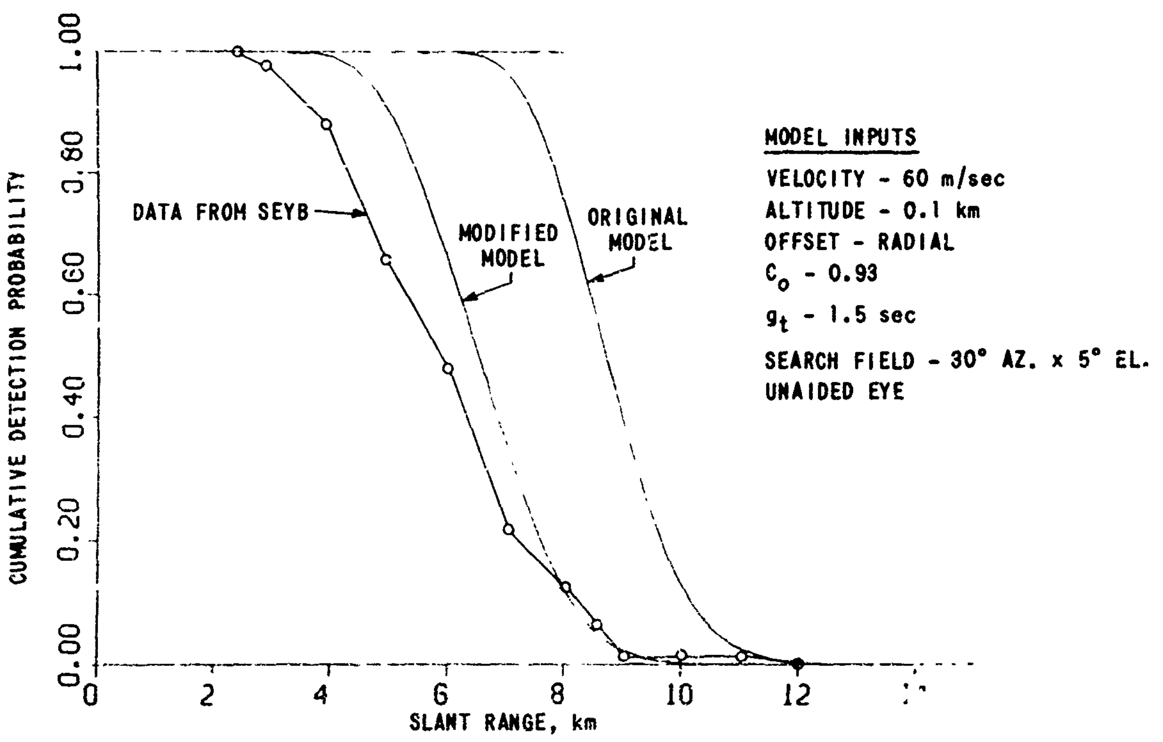


Figure 5a. Cumulative Detection Probability-Comparison of Model Results and Field Data with 21 KM Visibility

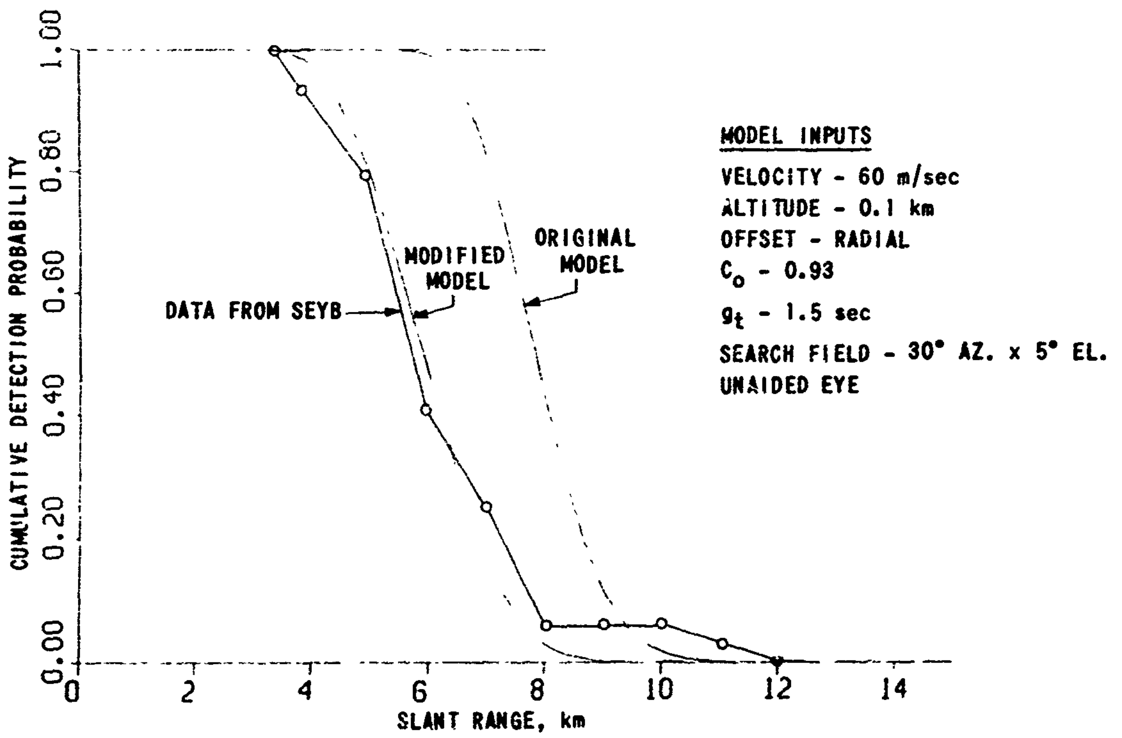


Figure 5b. Cumulative Detection Probability-Comparison of Model Results and Field Data with 17 KM Visibility

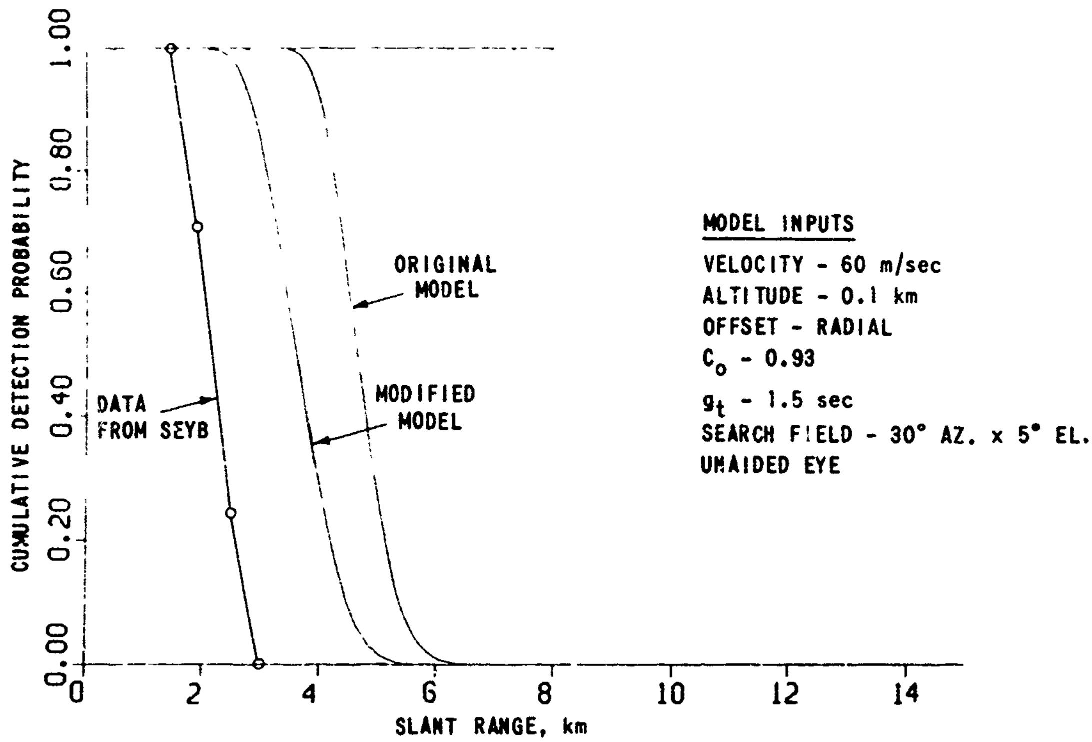


Figure 6a. Cumulative Detection Probability-Comparisons of Model Results and Field Data with 7 KM Visibility

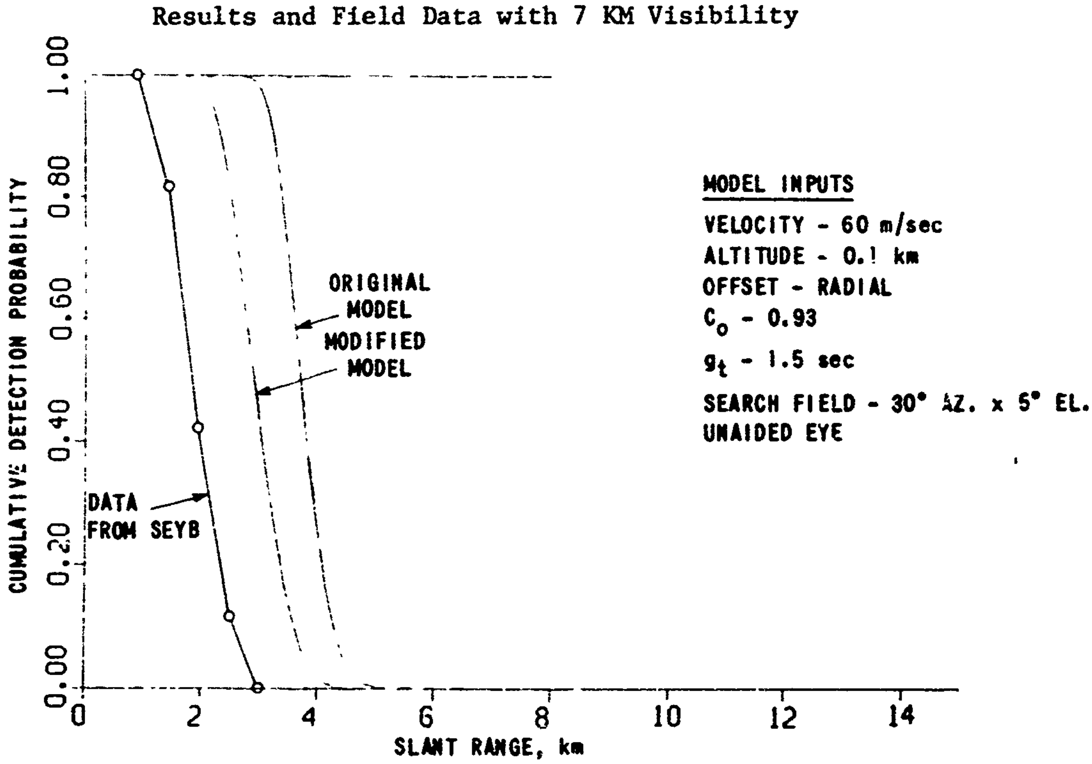


Figure 6b. Cumulative Detection Probability-Comparison of Model Results and Field Data with 5 KM Visibility

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APPENDIX A

The single glimpse detection probability ($\bar{g}$) is obtained by use of the relation:

$$\bar{g} = \int_0^{\pi} P(\phi_2'') \, g(M\phi_2'') \, d\phi_2'' \tag{A-1}$$

where: ϕ_2'' = real difference angle between target position and fixation point*

$g(M\phi_2'')$ = single glimpse detection probability

$P(\phi_2'')$ = probability density of ϕ_2''

M = magnification of optics (M = 1 for unaided search)

This appendix shows the procedure for generating the $P(\phi_2'')$ distributions as they depend on the independent distributions of target position and fixation point within a search field Ω_0. The situation is most easily understood by examining figure A-1. The two vectors representing target and fixation direction are unit vectors. All angles subscripted "1" are target coordinates, and "2" are fixation coordinates. The fixed frame x, y, z is that of the search field Ω_0.

* The difference angle ϕ_2'' is the same as θ' in the main text. As a matter of convenience, the notation used in this appendix and the main text were not forced to agree.

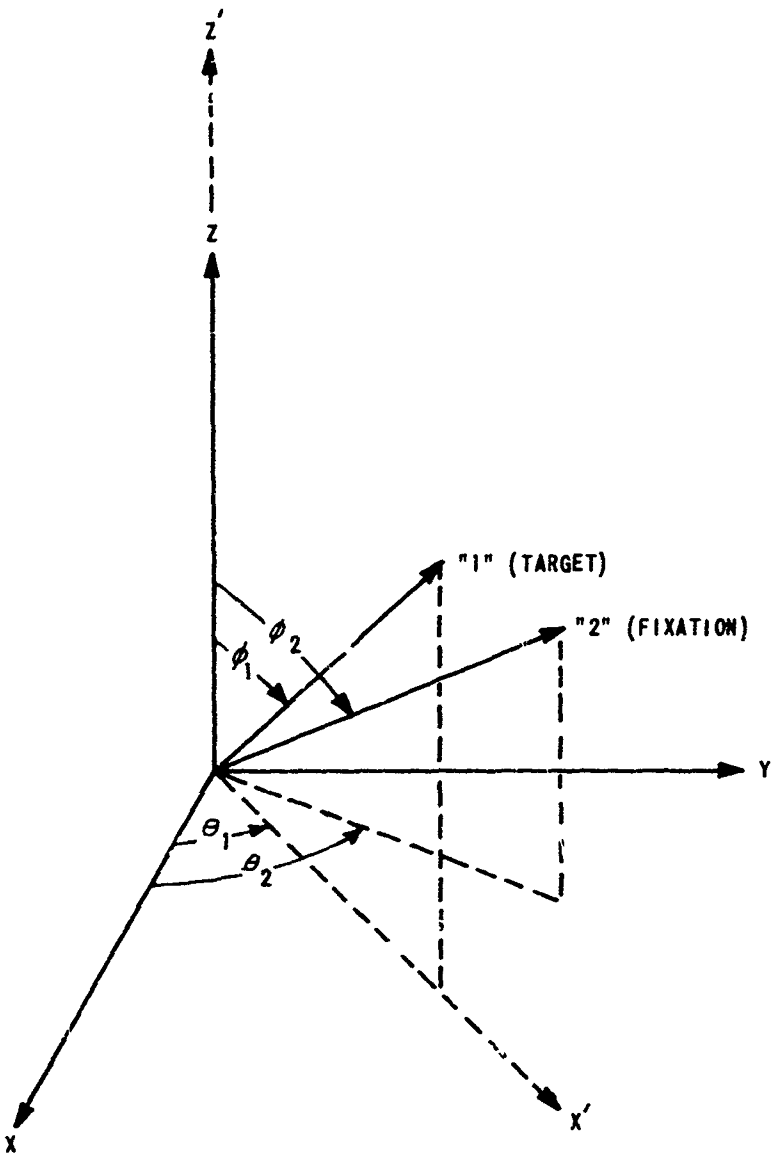

Figure A-1. Geometry of Target and Fixation Vectors

The distribution $P(\phi_2'')$ is found by integrating over the joint probability distribution of the two vectors. For a target vector within $d\Omega_1$, and a fixation vector within $d\Omega_2$, the joint probability can be written:

$$dP = P_1(\theta_1, \phi_1)\, P_2(\theta_2, \phi_2)\, d\Omega_1\, d\Omega_2 \tag{A-2}$$

$$= P_1(\theta_1, \phi_1)\, P_2(\theta_2, \phi_2)\, \sin\phi_1 \sin\phi_2\, d\theta_1\, d\phi_1\, d\theta_2\, d\phi_2$$

where P_1 , and P_2 are the distributions of the target and fixation respectively.

We wish to integrate out three coordinates in such a way as to leave only the coordinate ϕ_2''. Since ϕ_2'' is not among the four coordinates of Equation A-2, it is first necessary to transform coordinates.

The transformation consists of a coordinate rotation to provide that the new z direction will coincide with the target vector, thus establishing that the new ϕ coordinate of the fixation will be the desired difference angle. The transformation is carried out in two steps. First is a rotation about the z axis through the angle θ_1 to place the target vector in a new x', z' plane:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\theta_1 & \sin\theta_1 \\ -\sin\theta_1 & \cos\theta_1 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} ; \quad z' = z \tag{A-3}$$

Second is a rotation about the y' axis through the angle ϕ_1, to finally put the target vector in the new z'' direction:

$$\begin{pmatrix} x'' \\ z'' \end{pmatrix} = \begin{pmatrix} \cos\phi_1 & -\sin\phi_1 \\ \sin\phi_1 & \cos\phi_1 \end{pmatrix} \begin{pmatrix} x' \\ z' \end{pmatrix} ; \quad y'' = y' \tag{A-4}$$

Since ϕ_2'' is the desired difference angle, we formally replace θ_2, ϕ_2 with θ_2'', ϕ_2''. Equation (1) thus becomes:

$$dP = P_1(\theta_1,\phi_1)P_2(\theta_2,\phi_2)\sin\phi_1 \sin\phi_2''\, d\theta_1\, d\phi_1\, d\theta_2''\, d\phi_2'' \tag{A-5}$$

Integrating over θ_1, ϕ_1 and θ_2'' yields the density $P(\phi_2'')$:

$$P(\phi_2'') = \sin\phi_2'' \int \sin\phi_1 \left\{ \int P_1(\theta_1,\phi_1) \left[\int P_2(\theta_2,\phi_2)\, d\theta_2'' \right] d\theta_1 \right\} d\phi_1 \tag{A-6}$$

where the integrals are taken over all space.* Before the inner integral can be performed, it is necessary to establish the relation between the old and new coordinates. That is, Equation (A-6) specifies θ_2'', ϕ_2'' and it is necessary to know θ_2, ϕ_2 in order to evaluate P_2. The components of the target vector in both systems are written:

$$\left.\begin{aligned} x'' &= \sin\phi_2'' \cos\theta_2'' & \qquad x &= \sin\phi_2 \cos\theta_2 \\ y'' &= \sin\phi_2'' \sin\theta_2'' & \qquad y &= \sin\phi_2 \sin\theta_2 \\ z'' &= \cos\phi_2'' & \qquad z &= \cos\phi_2 \end{aligned}\right\} \tag{A-7}$$

*The information regarding the search field (Ω_0) is formally included in the distributions P_1 and P_2.

Elimination of all the components between Equations (A-3), (A-4), and (A-7) gives:

$$\begin{pmatrix} \sin\phi_2 \cos\theta_2 \\ \sin\phi_2 \sin\theta_2 \\ \cos\phi_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_1 & -\sin\theta_1 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\phi_1 & 0 & \sin\phi_1 \\ 0 & 1 & 0 \\ -\sin\phi_1 & 0 & \cos\phi_1 \end{pmatrix} \begin{pmatrix} \sin\phi_2'' \cos\theta_2'' \\ \sin\phi_2'' \sin\theta_2'' \\ \cos\phi_2'' \end{pmatrix} \qquad \text{(A-8)}$$

or

$$\left.\begin{aligned} \sin\phi_2 \cos\theta_2 &= \cos\theta_1 \cos\phi_1 \sin\phi_2'' \cos\theta_2'' - \sin\theta_1 \sin\phi_2'' \sin\theta_2'' + \cos\theta_1 \sin\phi_1 \cos\phi_2'' \\ \sin\phi_2 \sin\theta_2 &= \sin\theta_1 \cos\phi_1 \sin\phi_2'' \cos\theta_2'' + \cos\theta_1 \sin\phi_2'' \sin\theta_2'' + \sin\theta_1 \sin\phi_1 \cos\phi_2'' \\ \cos\phi_2 &= -\sin\phi_1 \sin\phi_2'' \cos\theta_2'' + \cos\phi_1 \cos\phi_2'' \end{aligned}\right\} \qquad \text{(A-9)}$$

The evaluation of $P(\phi_2'')$ in Equation (A-6) can now be carried out once the distributions (P_1 and P_2) are chosen.

It was attempted initially to assign uniform distributions to both P_1 and P_2 within the search field Ω_c and zero outside:

$$P_1 = P_2 = \begin{cases} 1/\Omega_o & (\text{inside } \Omega_o) \\ 0 & (\text{otherwise}) \end{cases} \qquad \text{(A-10)}$$

Unfortunately, the evaluation of $P(\phi_2'')$ proved to be much too time consuming on the computer and the choice of Equation (A-10) was abandoned.

As an alternative it was decided to specify the target location within the search field thereby eliminating two of the three integrations in Equation (A-6). Formally, we write:

$$P_1(\theta_1, \phi_1) = \delta(\theta_1 - \theta_T, \phi_1 - \phi_T) \qquad \text{(A-11)}$$

where δ is the Dirac delta function and θ_T, ϕ_T are the target coordinates. Equation (A-6) thus becomes:

$$P(\phi_2'') = \sin\phi_2'' \int P_2(\theta_2, \phi_2)\, d\theta_2'' \qquad \text{(A-12)}$$

The reader should not be misled by the seeming absence of the target coordinates from Equation (A12) since they do enter into the required transformation of Equation (A-9).

SEMICONDUCTOR LASER APPLICATIONS TO MILITARY TRAINING DEVICES

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Systems using semiconductor gallium arsenide lasers have been developed in-house to train military personnel in M-16 rifle weapon firing against both pop-up targets and scaled model aerial targets.

The pop-up target system consists of two parts: (1) a miniature laser transmitter which clips on the barrel of an actual M-16 rifle, and (2) detectors and a receiver to score weapon hits. The system may be used to save ammunition costs, and to teach the correct sight picture, trigger squeeze, posture, and breathing techniques. The trainee also uses his own weapon so he becomes quite familiar with its feel. Because the laser system is eye-safe, no elaborate range safety precautions are necessary. Safe training can be accomplished in inhabited areas with these systems. Since the simulation unit can shoot in excess of one million shots on a small commercial battery, more training can be accomplished at a very low cost.

The gallium arsenide laser diode emits a 150 nanosecond flash of infrared energy and is eye-safe. The radiation is at a wavelength of 9050 Angstroms (near infrared) at 25°C. The laser output is four watts of peak power. The beam is collimated by a single, simple double convex lens, and the beam diameter at 300 meters is approximately 15 centimeters. However, the beam may be adjusted to a larger or smaller diameter. The laser which acts as a transmitter is powered by a small commercial 45-volt battery which is usable for in excess of one million shots. The unit can either emit a single flash, or shot, or simulate the weapon's firing rate for a 20 round magazine. When the weapon is fired the infrared laser pulses are detected by a large area silicon photodiode. In the pop-up target configuration, detectors are fastened to a standard M-31A1 Army pop-up target, which is a silhouette of a man. No changes are necessary to the pop-up mechanism to adapt it for use with this laser weapon fire simulator. The receivers have a field effect transistor, FET, front end and have a minimum of low cost components. The system has a range in excess of 500 meters in sunlight. In addition, this system can provide a record of score. The pop-up target system and laser transmitter attached to an M-16 rifle are shown in figure 1.

The aerial engagement trainer system is used to train military personnel to engage aerial targets. The trainer is used to teach squad members to detect and identify hostile aircraft, estimate the range, speed and direction of the target, proper alignment of the sight to obtain the correct lead, and to continuously track and engage the target.

The scores for an entire squad firing at the target can be electronically totaled. The target is a 1/12 scaled model aircraft that is equipped with several silicon photodetectors. Lead angle is incorporated in the laser transmitter system by a mechanical swivel, which offsets the gallium arsenide laser transmitter at the lead angle which corresponds to the speed of the scaled model. The transmitter fires at the cyclic firing rate of the M-16 weapon and simulates the number of rounds in the weapons magazine. In the aerial engagement model, the

laser transmitter beam is shaped with an aperture or stop to a rectangular geometry. The rectangular beam enables the use of fewer photodiode detectors on the target. An electronic counter is used to score the number of hits on the target. A special feature to allow the student to get the proper sight picture for the various lead angles has also been incorporated. A Xenon flasher is located in the model's cockpit; when the student has the correct lead, the flasher is activated. This enables the student to see the correct sight picture for the various aircraft speeds prior to firing at the scaled moving target. The aerial engagement system is shown in figure 2.

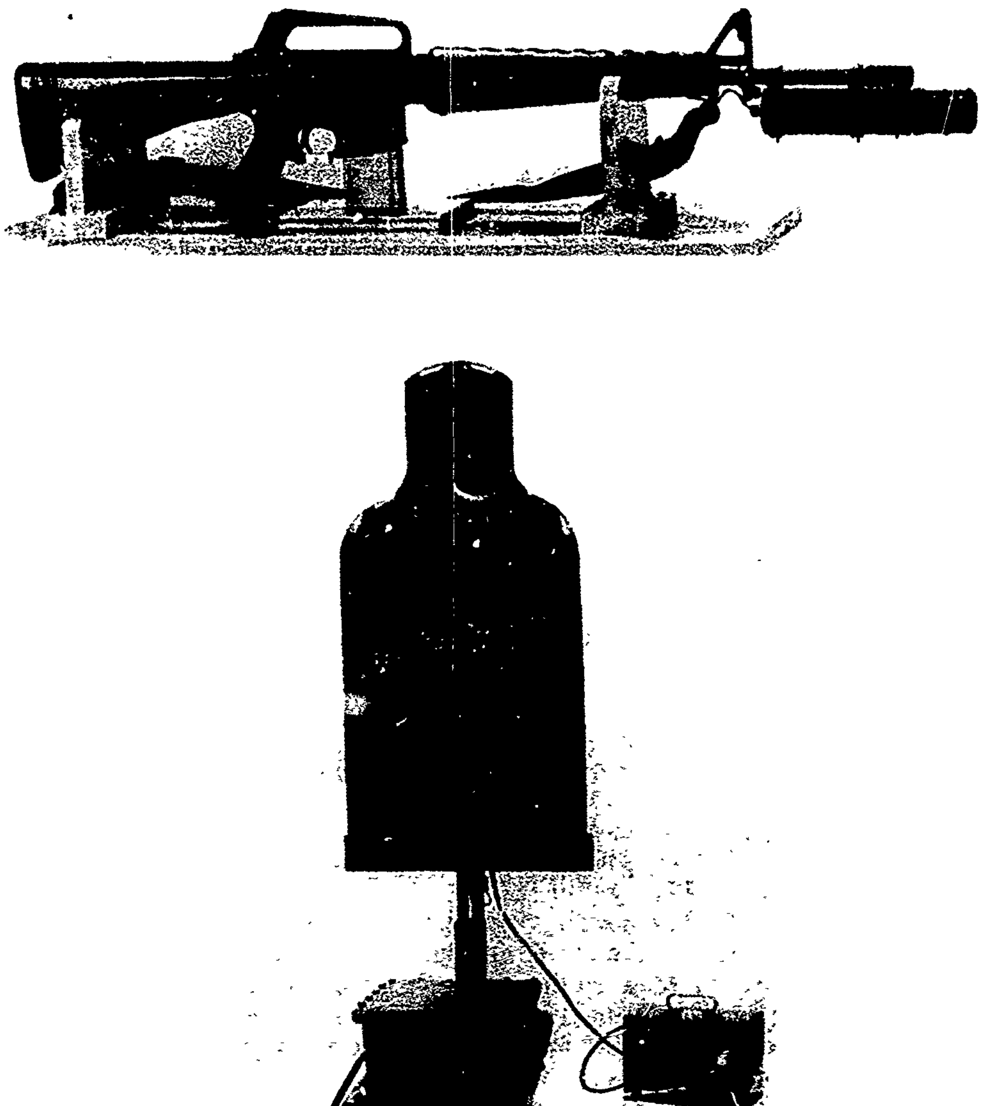

Figure 1. M-16 Rifle Laser Weapon Fire Simulator System

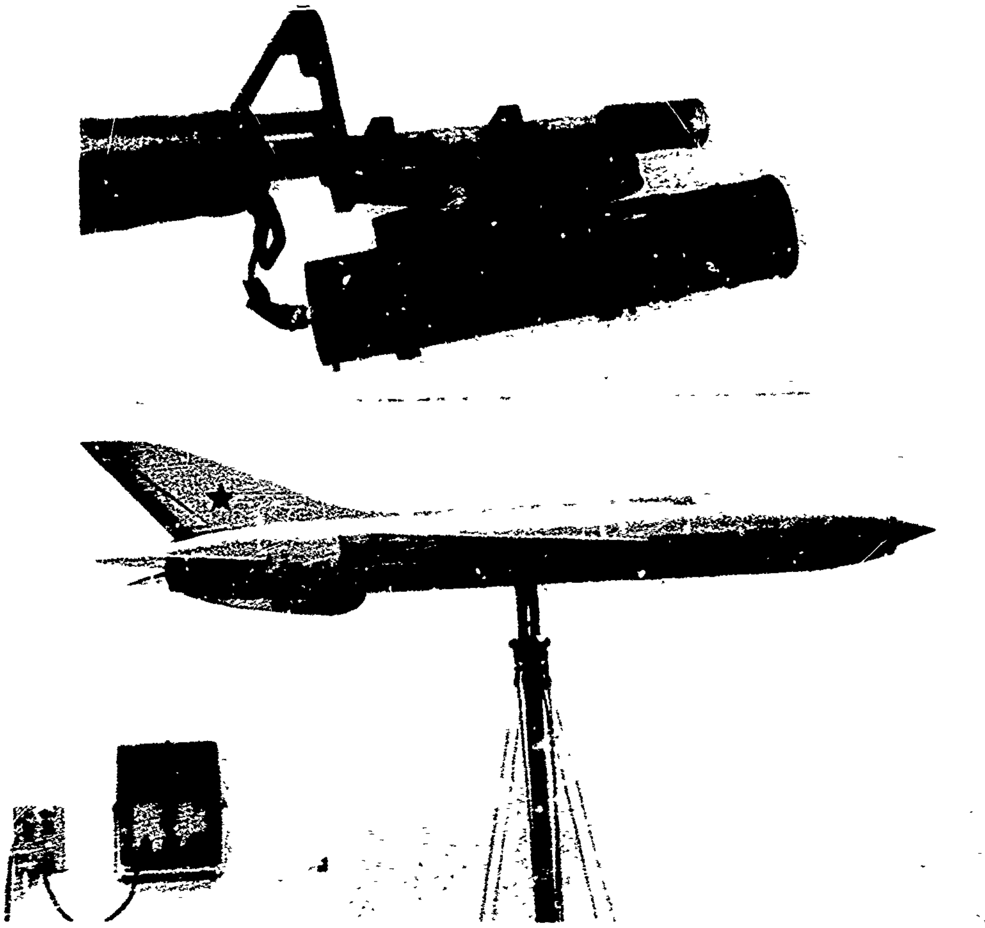

Figure 2. Aerial Engagement System

A study was performed at the U.S. Army basic training center at Fort Jackson, South Carolina, with the pop-up target system, to determine the effectiveness of a marksmanship training program of instruction using the laser weapon fire simulator as opposed to the present program of instruction utilizing live ammunition. The objective was to determine which combination of live ammunition and laser training will give the best training results. To determine the best results, scores on the live ammunition record fire range of each group wer[illegible]pared. [illegible]re 3 shows the results. Notice in all cases recruits t[illegible]d with the laser did as well, or better than soldiers trained exclusively with live ammunition, which costs six cents a round. It has been estimated that six million dollars in ammunition costs alone will be saved each year using this training device.

A moving target system using a semiconductor laser is now under development. In this system both the laser transmitter and a receiver are attached to an actual M-16 rifle. A corner mirror or retroreflector is attached to the moving man target. When the rifle is fired, an eye-safe laser pulse of near infrared energy is transmitted.

If the trainee's sight is on the target, the retroreflector will return most of the energy directly back to vicinity of the transmitter and receiver, even if the retroreflector is not directly on axis to the transmitter. The received pulse is amplified and actuates a tone indicating a hit. The batteries and a small speaker are in the rifle's magazine. The retroreflector is placed in front of the man or dummy so that it will be necessary to lead the man to get a hit. If the dummy moves at varying speeds, apertures are used to shutter or unshutter the appropriate retroreflector. The trainee gets instant scoring without complicated radio links to relay back the firing results. In this system the retroreflector requires no target maintenance; it only needs to be kept reasonably clean. At closer ranges high gain materials can replace the retroreflector. This system allows programming for the dummy to move at various speeds. The system is safe and requires less range personnel to operate than a standard rifle range, and saves the cost of ammunition.

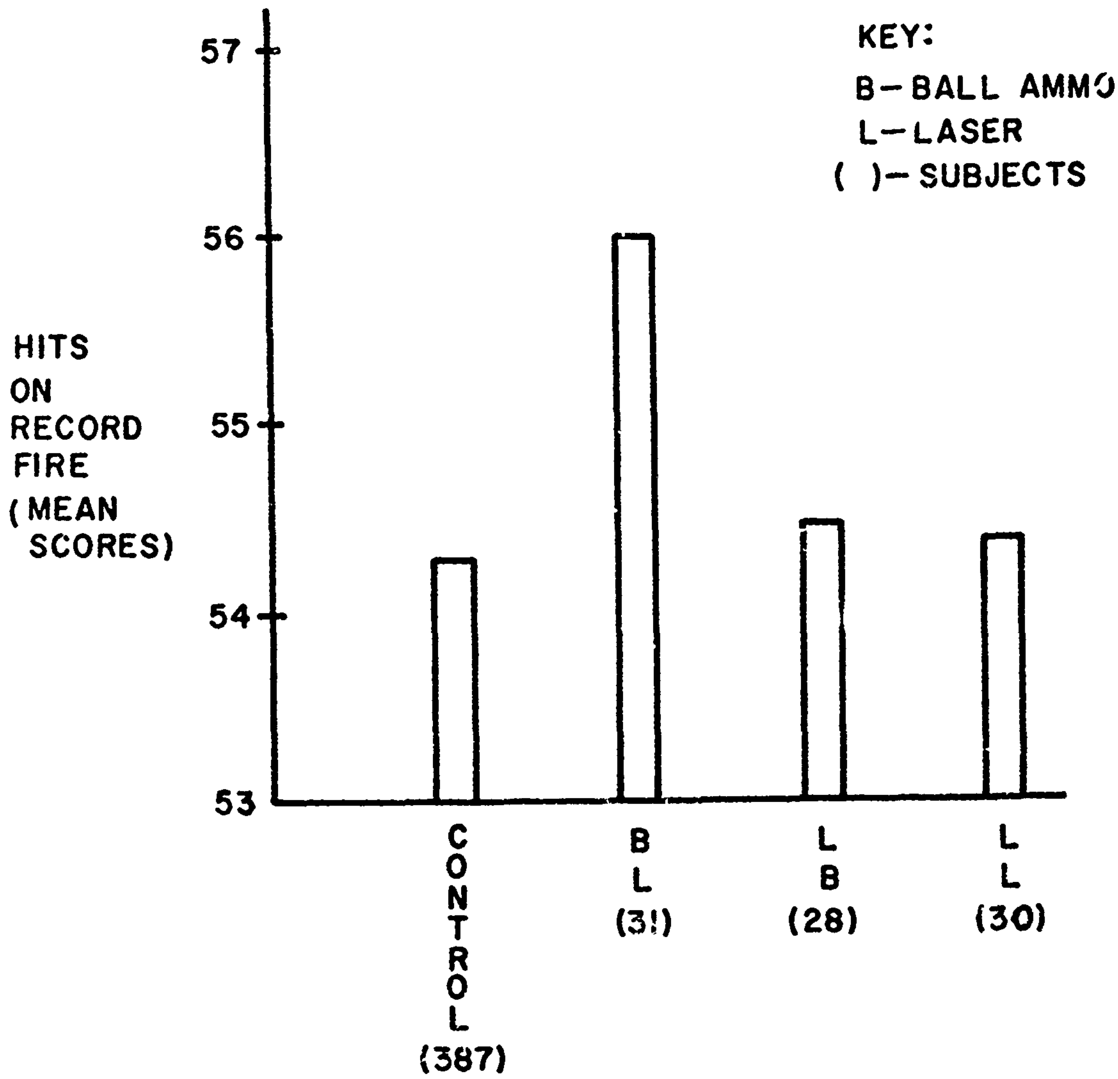

Figure 3. Results of Laser Rifle Transfer of Training Tests at Ft. Jackson, S.C.

DIGITAL RADAR LAND MASS DISPLAY SIMULATION

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SUMMARY

Simulation of radar Plan Position Indicator (PPI) displays is a critical requirement in training navigators, pilots, and bombardiers to identify targets and to interpret radar return signals from terrain and cultural areas. Present radar land-mass simulators use a transparency data base read by a flying spot scanner. This approach is limited by the difficulty in preparing the transparencies to meet the required resolutions and by the difficulties in updating transparencies to reflect cultural changes such as new bridges, large buildings, piers, and other features that are prominent in a radar display and that are key factors in training a pilot, navigator, or bombardier to quickly recognize his target and position.

The Digital Radar Land-Mass (DRLM) approach solves the resolution and flexibility problems. In the digital approach, terrain and cultural features are reduced to a mathematical representation, such as line segments, and are stored in a digital memory. A radar sweep is defined. Representative radar return signals are calculated, based on the digitally stored data, and then are displayed on a PPI radar scope.

An experimental laboratory model Digital Radar Land-Mass Display Simulator was developed and evaluated. Terrain and cultural features (boundaries) were represented as line segments, digitally defined and stored by the Cartesian coordinates (x, y, and z) of the line end points. Based on aircraft position, a general-purpose digital computer defines a radar scan area and transfers the area data lines to a high-speed core memory. This memory is read once per sweep (PRF) by a special high-speed digital processor that selects the data lines intersected by the sweep and determines the point of intersection. The intersections are then ordered relative to increasing ground range (the sweep profile) and applied to a video processor, which modulates the profile for radar and other effects (shadow, incidence angles, earth curvature, etc.), and develops an intensity modulated sweep signal that is displayed on the PPI. The system processing rate is a line per microsecond. Thus, the system has a basic capability of processing 4000 data lines per real-time (4-millisecond) sweep.

The PPI display resulting from the laboratory system is shown in Figure 1. This is a time exposure of a real-time PPI scan. The scan rate is 1' scans per minute. Aircraft altitude is 14,000 feet and the sweep range is 45 n. mi. The data base for this display uses 4000 data lines to define reflectivity boundaries of cultural areas; such as, San Francisco, Berkeley, Oakland, San Jose, etc., and to define terrain elevation features such as the Santa Cruz and Diablo mountain ranges, Mt. Diablo, Mt. Tamalpais, etc. The data base also has 1000 data points that represent radar point source targets; such as, radio towers, buildings, ships, storage tanks, etc. The system allows complete freedom of motion over the data base in real-time. Elevation can be varied from zero to 30,000 feet, and the display accurately depicts radar shadow slant range effects, incident angle effects and shadow.

The conclusions of this project were: (1) the digital approach provides a cost-effective means for achieving the flexibility and resolution required in radar operator training simulators; (2) the ridge/valley and cultural boundary line approach provides a realistic three-dimensional real-time display capability; and (3) the line approach provides a significant reduction in the amount of data that must be stored and processed for a whole training mission.

Figure 1. The San Francisco Bay PPI Display

MATHEMATICAL MODEL AND DEFINITIONS

Terrain and cultural features are represented in the data base by contiguous line segments defined by the x, y, and z of their end points. Each line segment (figure 2a) defines a boundary between areas of different radar reflectivity and/or a terrain ridge or valley line. The reflectivity and radar texture code (Codes A, B, and C of figure 2a) for the right side and the left side of each line, as one goes from point to point through the data base, is stored with each line segment. Targets are points source features (smaller than radar beam width) that have a high reflectivity. Examples are ships, oil tanks, buildings, transmission line towers, etc. These are stored as independent points (x, y, and z) along with a code that defines target size and reflectivity.

A scan is defined as the complete picture seen by the radar from its current position. A sweep is one line of a scan and is identified with the radar pulse return signal. Assuming an aircraft ground position of x_A and y_A relative to a data base and a sweep line as defined by cos θ and sin θ, then the distance of the n^{th} data point from the sweep line (figure 2b) is

$$d_n = (y_n - y_A) \cos \theta - (x_n - x_A) \sin \theta. \qquad (1)$$

The ground range from the sweep origin (x_A, y_A) to the intersection of the distance vector, d_n, is

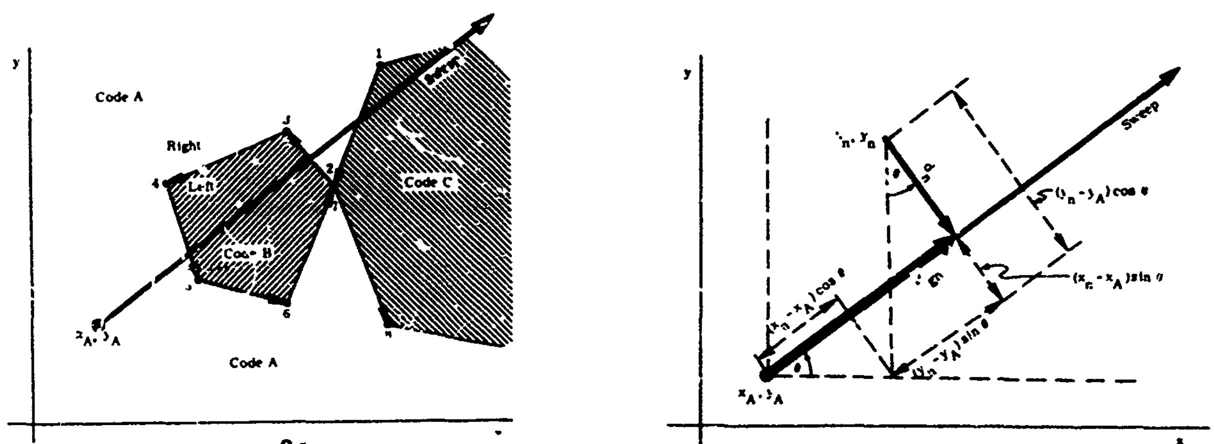
$$R_{gn} = (x_n - x_A) \cos \theta + (y_n - y_A) \sin \theta. \qquad (2)$$

The relative signs of d_n and d_{n+1} define when the sweep line intersects a data line (i.e., opposite signs indicate an intersection while the same signs indicate a no hit). The ground range to the intersection and the elevation of the intersection are determined by linear interpolation using d_n and d_{n-1}.

The sign of d_n also defines the direction that the sweep line crosses a data line. The reflectivity and texture on each side of a data line have been consistently coded right and left as we go from point to point. Thus, a positive d_n tells us that the right-hand code should be initiated--while a negative d_n specifies the left-hand code.

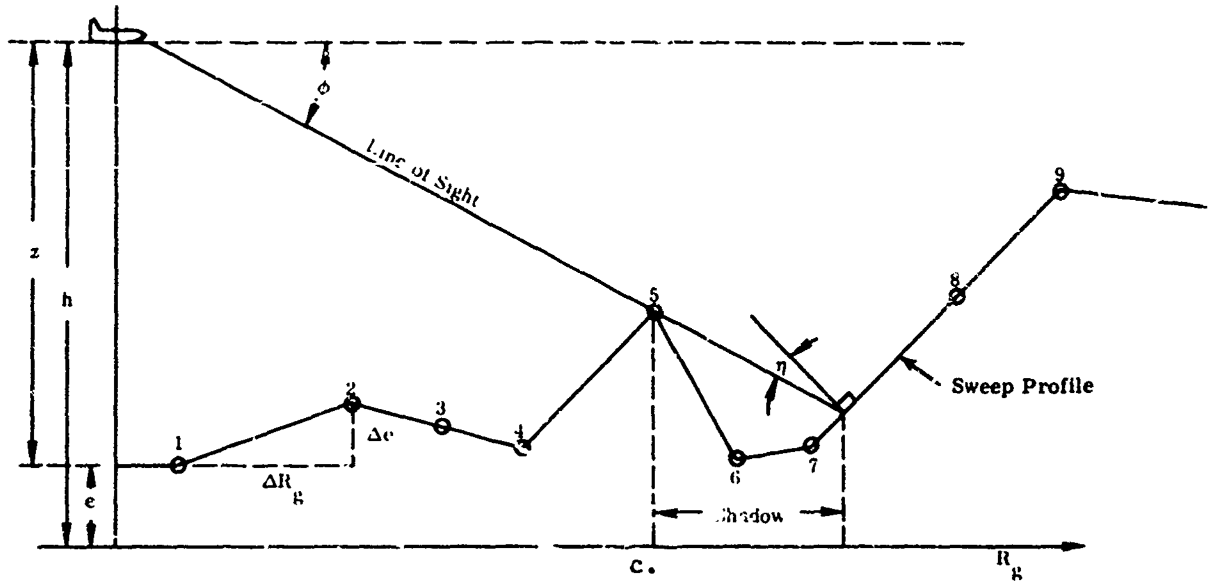
A target processor solves the same equations for d_n and R_{gn}. A target echo is generated when the sweep line passes within a half beam width of the target. This is defined by detecting when d_n is within a graduated band pass around zero.

The intersection points, when ordered relative to increasing ground range, describe an elevation and code change sweep profile as illustrated in figure 2c. Points 1, 2, 3, etc., are intersections or targets, and each point has encoded a ground range, elevation, and a reflectivity or texture change.



2a. 2b.

Figure 2a. and 2b. System Geometry



c.

Figure 2c. System Geometry

The intensity of a radar return signal will be a function of the reflectivity of the surface (this is the stored data) and the angle of incidence between the surface and the look angle ϕ. The intensity will vary as the cosine of the incidence angle η of figure 2c.

$$\cos \eta = \frac{(h - e)\, \Delta R_g + R_g\, \Delta z}{R_s\, M} \tag{3}$$

where

$$M = \sqrt{\Delta R_g^{\,2} + \Delta z^2}$$

Earth curvature must be accounted for. The change in terrain elevation as a function of earth curvature is approximately

$$\Delta z_e = \frac{R_g^{\,2}}{2\rho} \tag{4}$$

where R_g is ground range and ρ is the mean earth radius.

The radar return signal position on the PPI is a function of slant range—not ground range. The slant range is

$$R_s = R_g \cos \phi + (h - e) \sin \phi \tag{5}$$

Radar shadow is an area where there is no return signal. In figure 2, this is the area between point 5 and where the beam strikes the surface between points 7 and 8. The intensity is zero. The start of a shadow is defined by an increase in the angle ϕ as one progresses from point to point along the sweep profile. The end of a shadow is indicated by the point where ϕ becomes less than the value at the start of the shadow.

Finally there is a number of special radar effects that were not simulated in the present system. Some of these are (1) Radar beam width integration; (2) specular surface returns; (3) pulse width integration; and (4) directional targets. In general, these effects can be readily derived from the geometry defined previously.

THE LABORATORY SYSTEM

Figure 3 is a block diagram of the laboratory breadboard system that was developed to prove the feasibility of a real-time radar display system based on the approach described in the preceding section. A manual input control, "joy stick," defines the location, elevation, heading, and velocity of the aircraft. A small general purpose digital computer then selects from the region or training data base, stored on a disc file, the data lines and targets seen by the radar scan and loads these into one of two scan memories—one memory is being read while the other is being loaded with data for the next scan.

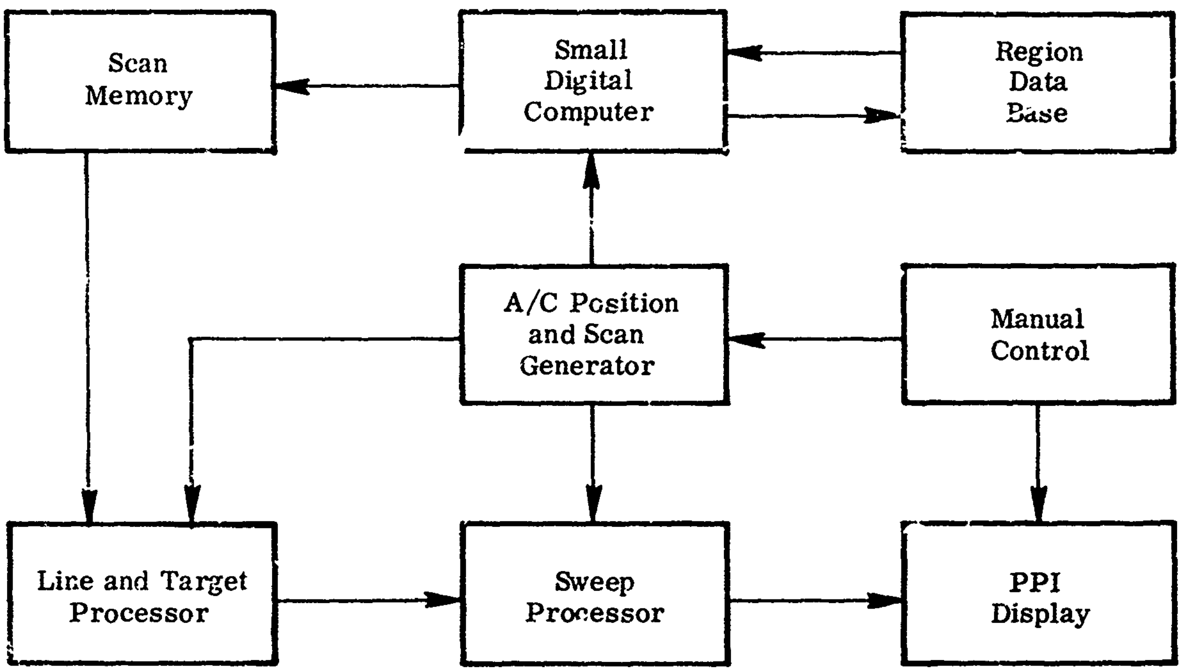


Figure 3. The Laboratory System

The line and target intersection processor reads the scan memory at a point per microsecond and computes the sweep profile, figure 2c. This unit is a special high-speed dedicated digital processor that employs parallel and pipeline processing techniques. The processing technique is illustrated in figure 4. In the first microsecond, a data point and sweep data are read in and corrected for aircraft position. In the next microsecond, d_n and R_{gn} (Equations 1 and 2) are computed. If the data line intersects the sweep, the ground range and elevation of the intersection are determined by an interpolation process which also takes one microsecond.

Targets in the current laboratory system are processed in a parallel unit in a similar manner. The interpolator unit is not required in the target channel because when d_n is within a graduated band about zero, a hit is scored and the computed range is the true ground range.

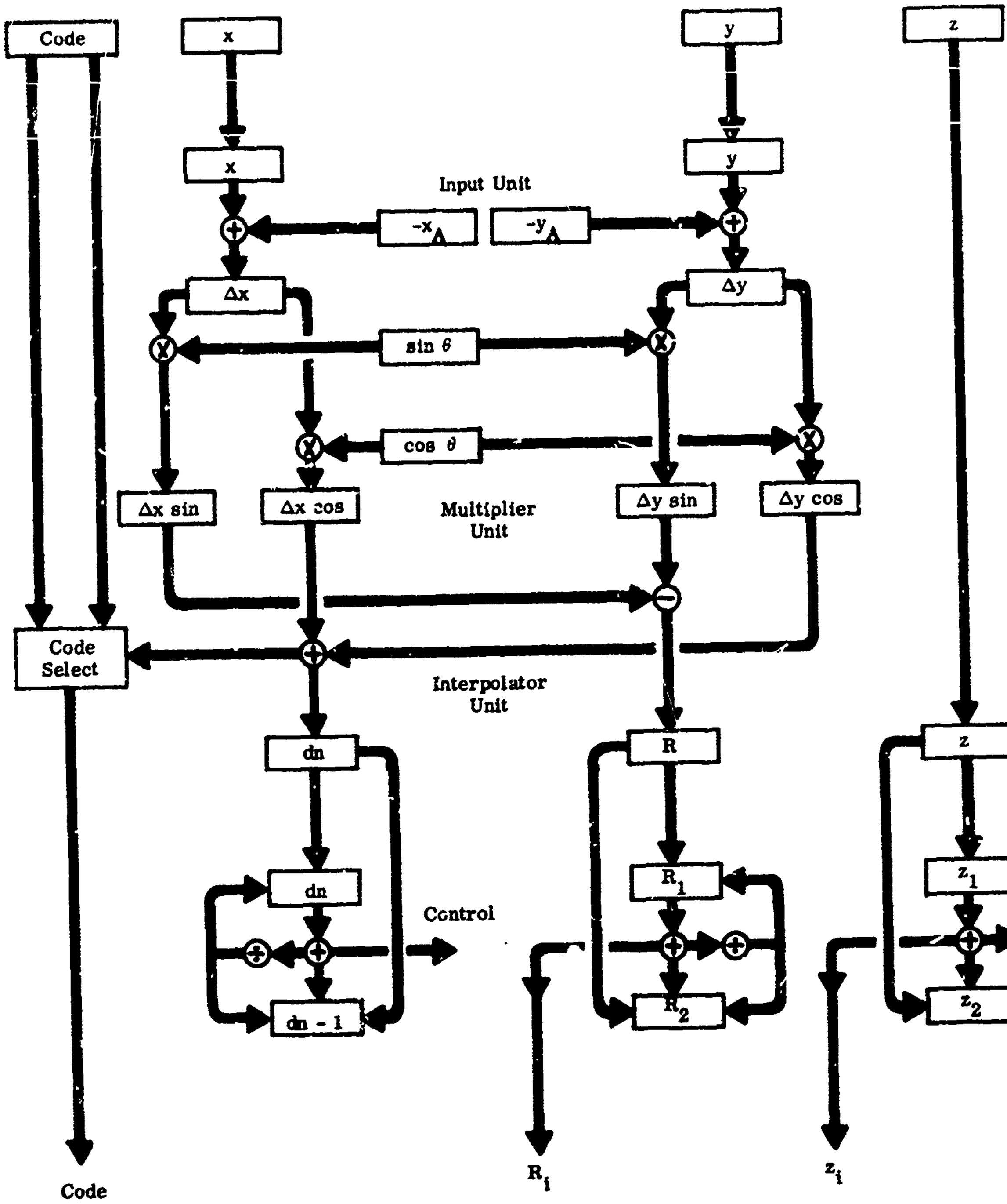


Figure 4. The Line and Target Processor

The outputs are then ordered relative to ground range by reading the code and elevation data into a random access memory using ground range as the address. Again two memories are used—one is receiving and ordering data while the other, which contains the previous sweep data, is being read by the sweep processor.

In the sweep processor, figure 5, a ground range counter reads out the sweep profile from the output memory of the line and target processor. In the current laboratory system, the sweep processor is a high-speed dedicated analog unit. This is currently being replaced by an all-digital unit. The digital sweep profile is converted to an analog profile and earth curvature, slant range, incident angle, and shadow effects are computed. The multiplication, division, and modulator functions are accomplished with variable transconductance multipliers having a full power bandwidth of greater than one megacycle.

The psuedo-noise generator is a closed-loop shift register that generates a psuedo-random sequence of ones and zeros. Different texture effects are achieved by varying the sequence frequency. The P-N code, when read out of the memory, will gate in one of three codes. With each output is a 3-bit digital word that defines the radar reflectivity level. The P-N sequence is modulated by the product of the reflectivity level and cos η in the video modulator. The output of the modulator is the PPI video intensity signal.

The computed slant range, R_δ, is multiplied by sin θ and cos θ providing the x and y deflection voltages of the sweep. Thus the sweep is driven directly by slant range and simulates integration and inversion effects.

CONCLUSIONS

Prior to the start of the DRLM effort, it was known that a digital approach would provide the advantages of flexibility and ease of modifications mentioned in the Summary. In addition, it was recognized that the digital approach could provide a very significant improvement in reliability and in maintenance cost reductions in comparison with the current analog systems. The question that had to be answered was, "Can the digital representation of the terrain and the computations required to produce an accurate, realistic, real-time radar display simulation be performed in a cost-effective manner?" The results of the effort provide a fully verified "Yes" as the answer to this question.

The PPI display resulting from the current laboratory system is adequate for some training missions. However, many training missions will require a display of higher density and resolution. A laboratory development program is now underway that will provide a factor of improvement greater than ten over the current system. First, a data input filter is being developed that will allow an input data density of 16,000 lines or targets per scan. Second, a digital sweep processor is being developed that will divide a one millisecond sweep into 1000 elements and compute slant range, incidence angle, shadow, and earth curvature for each element. The current laboratory system is limited to 4000 lines and targets per scan and 512 elements on a 4 millisecond sweep. The improved system will use the same processing techniques and current state-of-the-art logic units as are used in the current system.

Special processors for beam width integration, specular returns, directional targets, and other radar effects are being implemented. With these improvements, it is predicted that the Digital Radar Land Mass approach can meet all radar operator training requirements.

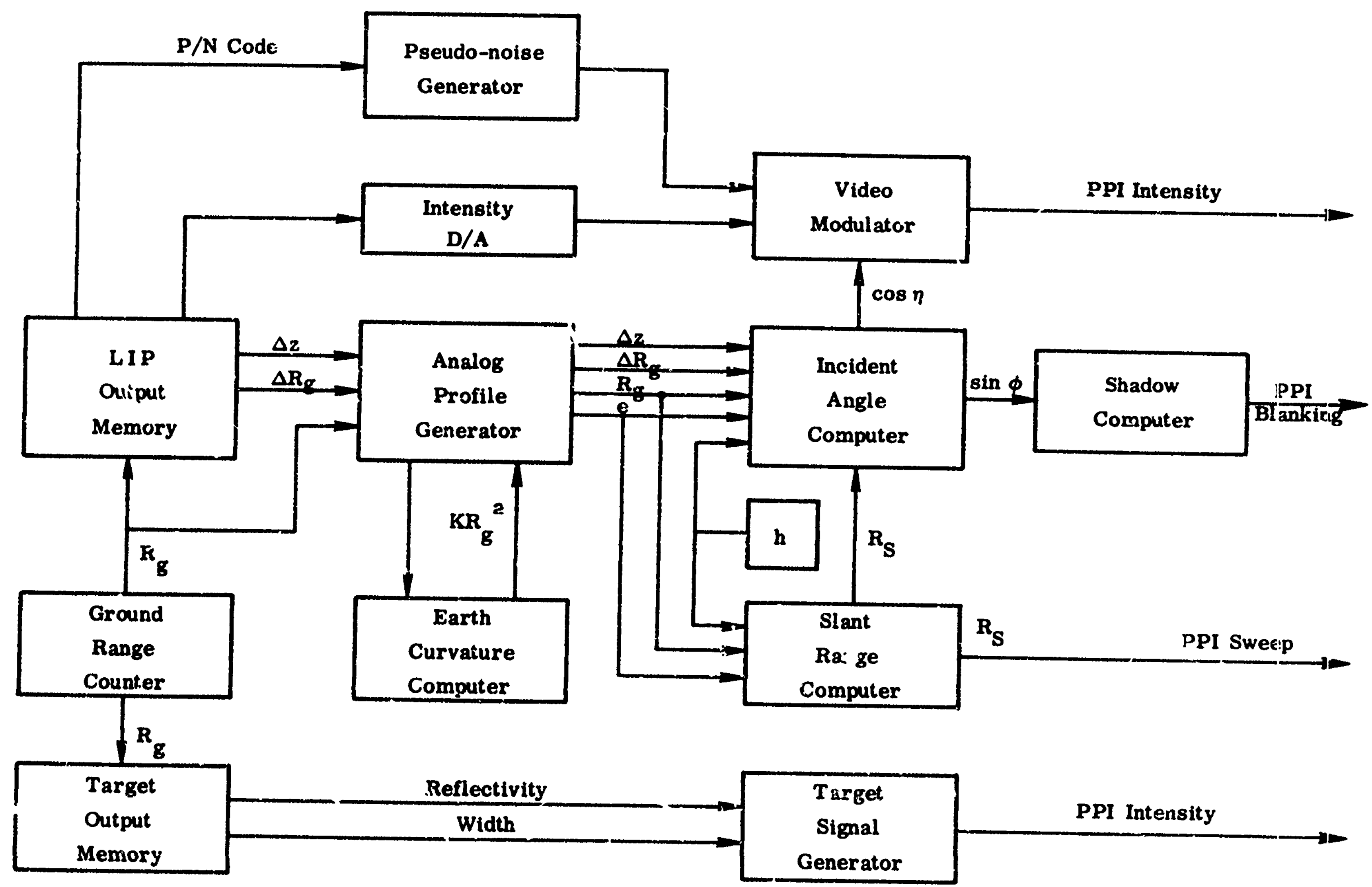


Figure 5. The Sweep Processor

DESIGN AND PRODUCTION OF ANTIREFLECTION COATINGS

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Multilayer thin films are widely used in science and industry for control of light. Optical surfaces having virtually any desired reflectance and characteristics may be produced by means of thin film coatings. These films are usually deposited on substrates by high vacuum evaporation. The applications range from high reflectance laser mirrors to high transmittance optical systems including interference filters, hot and cold mirrors, broad band reflectors and narrow band reflector, all of which are used in visual simulation systems and training devices. This paper will be concerned with the design and production of multilayer, dielectric, antireflection coatings for use in the visible spectrum from 400 to 700 nanometers.

Everyone who has seen colors exhibited by films of oil on water, and by soap bubbles, has observed the striking phenomena of interference in thin dielectric films. Interference in layers having fractional wavelength optical thicknesses remained a scientific curiosity until the 1930's when methods were developed for depositing one or more layers of solid dielectric of controlled thickness. The most common technique consists in vaporizing the dielectric in an oven, placed in a highly evacuated vacuum chamber, and condensing the vapor on the relatively cool surface of the substrate. Layer after layer of different materials of any desired optical thickness can be deposited in this way. The performance of dielectric thin film coatings is predicted well by a theory to be described later, which treats each layer as a homogenous medium, with sharply defined plane boundaries.

The nomenclature for a three-layer thin film coating is illustrated in figure 1. The n's are the five indices of refraction of the various media involved (the three layers plus the medium and substrate). The L's are optical thicknesses of the three layers (the medium and substrate are assumed to have infinite thickness). An optical thickness is simply the product of the physical thickness and the material's index of refraction. Note the S and P indicated on the incident wave; they are representative of polarization perpendicular or parallel respectively to the plane of incidence. The reflectance is the square of the absolute magnitude of the amplitude ratio of the reflected wave over the incident wave.

The numerical values of the reflected and transmitted wave amplitudes are governed, in general, by the boundary conditions on Maxwell's equations. More specifically, Fresnel's equations, which apply to the dielectric case, lead to a matrix formulation of thin film theory which lends itself very well to the computation of multilayer problems. The pertinent matrix relationships for normal incidence are given in figure 2.

In figure 2, M is the transfer matrix of the entire multilayer coating, r and t are the reflection and transmission coefficients,

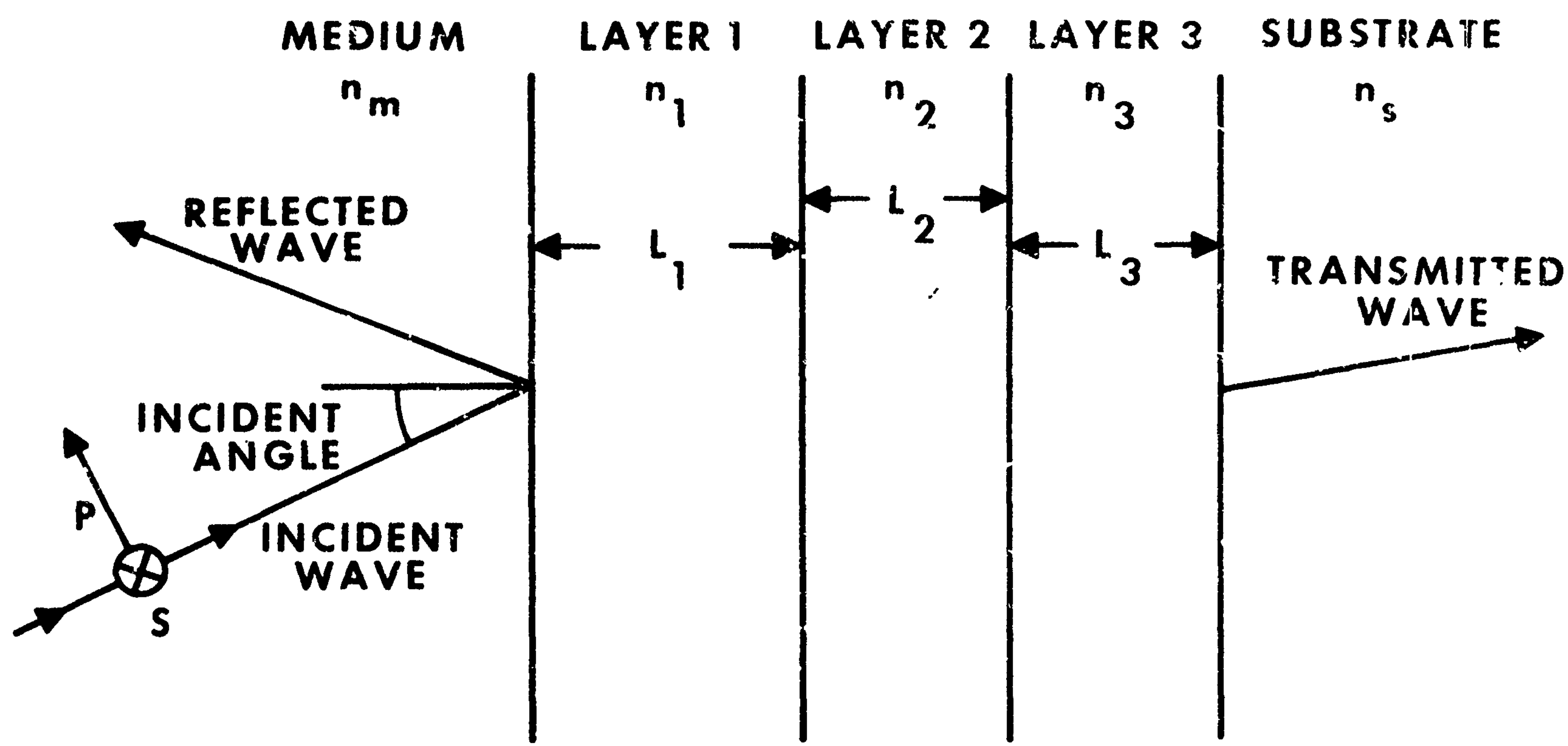

Figure 1. Schematic of Three-Layer Coating.

MI is the transfer matrix of layer i, j is the square root of minus one, Li is the optical thickness of layer i, and λ is the vacuum wavelength of the incident light.

Consider a system comprised of N layers. The problem is to find the reflectance at vacuum wavelength λ. Assuming the optical thicknesses are known the matrices MI can be obtained and subsequently the transfer matrix of the entire thin film system by simple matrix multiplication -- M_1 times M_2 times M_3, etc. times Mn. Substitution of M into equation 1 yields a known relation between r and t, the reflected and transmitted amplitudes. Another relation relating r and t is that $|r|^2 + |t|^2 = 1$ assuming no absorption. Using these two relations, a value for reflectance can be calculated.

For other than normal incidence the equations become more complex. The effect of incoming polarization must be taken into account as well as the angle of refraction at each surface boundary. Rather than repeat tedious calculations, I will just state that I have written a simple program for our programmable desk calculator, which can compute the reflectance from up to three-layer thin films, for incoming light of either S or P polarization at any angle of incidence. The program is designed to compute reflectance for wavelengths from 400 to 700 nanometers in 10 nanometer steps. The results, together with the input data, are printed out in tabular form.

Figure 3 is a sample printout which just repeats the input data. Figure 4 contains several curves drawn from data supplied by the calculator printout. The curve marked "Glass" is the expected constant 4% reflectance from a dielectric of index 1.5. Note no effort has been made to include dispersion or absorption in any of these or the following computations. The MgF_2 curve is the spectral reflectance as computed for a single 125 nanometer thick coating of index 1.38 on substrate of index 1.5. The triple layer curve is the reflectance for 125 nm MgF_2 index 1.38 + 250 nm Nd_2O_3 index 2.00 + 125 nm CeF_3 index 1.60 on glass of index 1.50.

Figure 5 contains similar curves where the material and thicknesses are the same as the triple layer coating on the previous slide, but angle of incidence and incident polarization have been varied. Note that reflectance of uncoated glass at 30° S polarization is 5.77% and at 60° P polarization is 0.18%. Obviously you are not always better off with AR coatings. Another point of interest, which is not immediately obvious from these curves, is that the region of lowest reflectance shifts toward the shorter wavelengths as the angle of incidence increases. This, by the way, is also true of narrow band interference filters.

The production of these coatings involves the deposition of controlled thicknesses of various materials on the desired substrate. Fortunately the thickness of each layer can be monitored individually without breaking the vacuum. In figure 6 the reflectance as a function of single layer film thickness for a single wavelength is plotted. The upper curve is for a film of higher index than the substrate and the lower curve is for a film of lower index than the substrate. The important characteristic of these curves is not so much the absolute

$$1.\quad \begin{bmatrix} 1 \\ n_m \end{bmatrix} + \begin{bmatrix} 1 \\ -n_m \end{bmatrix} r = M \begin{bmatrix} 1 \\ n_s \end{bmatrix} t$$

$$2.\quad M = \prod_{i=1}^{N} M_i$$

$$3.\quad M_i = \begin{bmatrix} \cos 2\pi L_i/\lambda & -j\frac{1}{n_i}\sin 2\pi L_i/\lambda \\ -jn_i \sin 2\pi L_i/\lambda & \cos 2\pi L_i/\lambda \end{bmatrix}$$

Figure 2. Equations relating Reflection and Transmission of a Multilayer Coating

THREE LAYER COATING

$n_m = 1.000$	$L_1 = 125.00$
$n_1 = 1.380$	$L_2 = 250.00$
$n_2 = 2.000$	$L_3 = 125.00$
$n_3 = 1.600$	
$n_s = 1.500$	

ANGLE 60.00

POLAR 1.0

Figure 3. Sample Input Data Reprinted by Desk Calculator.

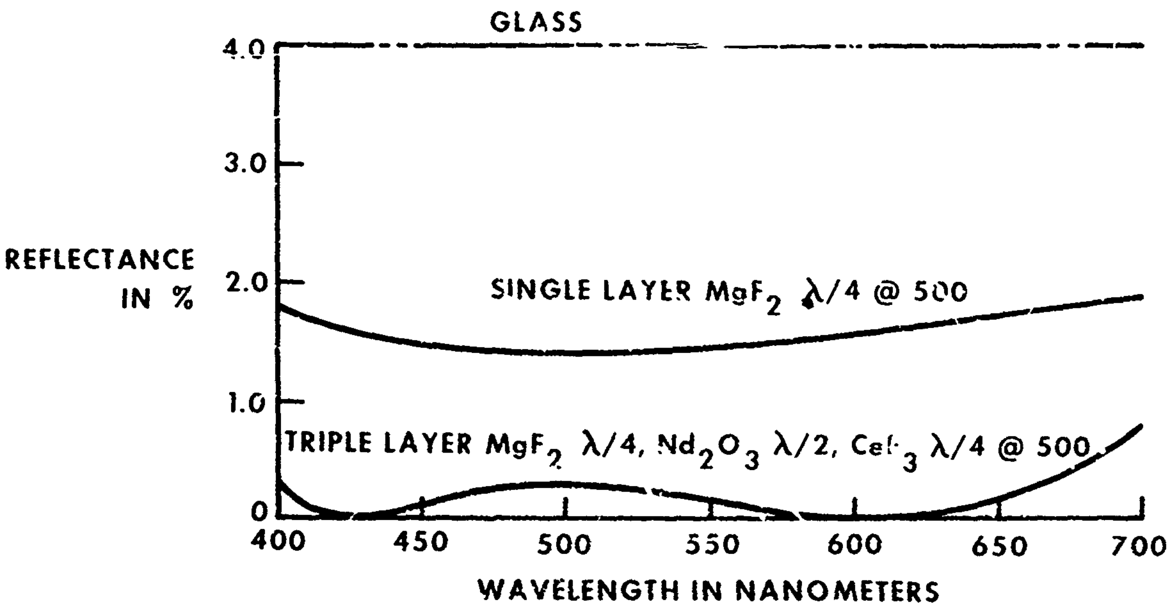

Figure 4. Reflectance as a Function of Wavelength at Normal Incidence.

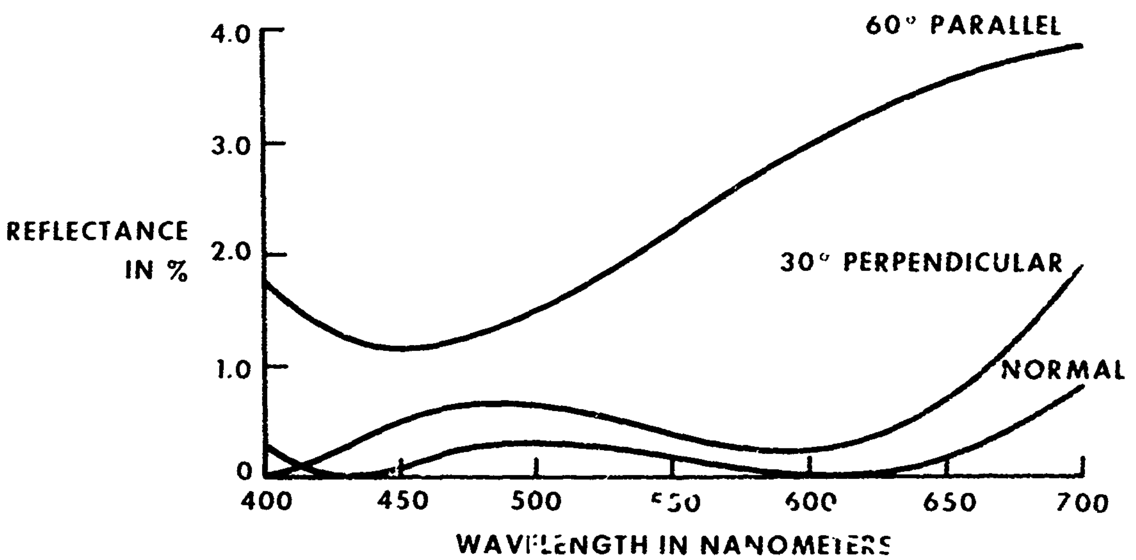

Figure 5. Spectra Reflectance as a Function of Angle of Incidence and Polarization.

value of the reflectance but the fact that they periodically reach maxima and minima. Therefore, if each layer is deposited on a test plate, the reflectance can be measured continuously at the design wavelength, while the coating is taking place, and the coating process can be stopped when the desired optical thickness is reached. If other than quarter wave multiples of thickness are desired, the monitoring wavelength can be changed to other than the design wavelength where the thickness would be in multiples of quarter wavelengths. In figure 7, the monitoring system which we were designing and installing at the time this paper was written, is pictured. Note that the test piece is apertured so that only the area being looked at by the viewing system is exposed to the coating material. As different materials are coated the test piece is manually rotated to expose a clean area. The substrate is continuously rotated off-center to allow uniform deposition during coating. We expect to achieve uniformity in optical thicknesses to 0.05% (1 Angstrom). Rotating offset fixtures are the only way to achieve this uniformity using thermal source with non-uniform distribution. The height of the substrate above the source should be approximately 25 cm with a 17 cm offset to center of substrate. The maximum non-uniformity will then be a linear function of the number of revolutions. Trade-offs on coating time and maximum RPM of substrate lead to an ideal coating time of approximately 2 minutes per layer. The test piece should be placed such that the area being coated has the same geometry as the center of the substrate. By having several sources available for deposition, many layers can be coated without breaking vacuum.

The application of multilayer thin film antireflection coatings in visual simulation systems and displays are many. The desire for high luminance, high contrast displays generated by many surface optical systems is satisfied in two ways by antireflection coatings. The first obvious effect is the increase of total light transmitted through the optical system. The second, not so obvious, effect is the suppression of out of focus ghost images which tend to degrade both the contrast and overall optical quality of the image. A straightforward calculation, assuming normal incidence at each surface, for a 32 surface optical train yields a transmission of 27% for uncoated glass, 62% for single layer MgF_2 coatings, and 94% for the specific three layer coating discussed above.

Our experimental investigations are presently directed toward durable antireflection coatings on low index substrates such as plastics. As of the time this paper was written, several experimental runs had been made with one, two, and three layer coatings. Since our results were incomplete, they are not reported in this paper.

Future work will also be directed toward programming up to 50 layers and production of laser mirror coatings, hot and cold mirrors, and narrow band interference filters.

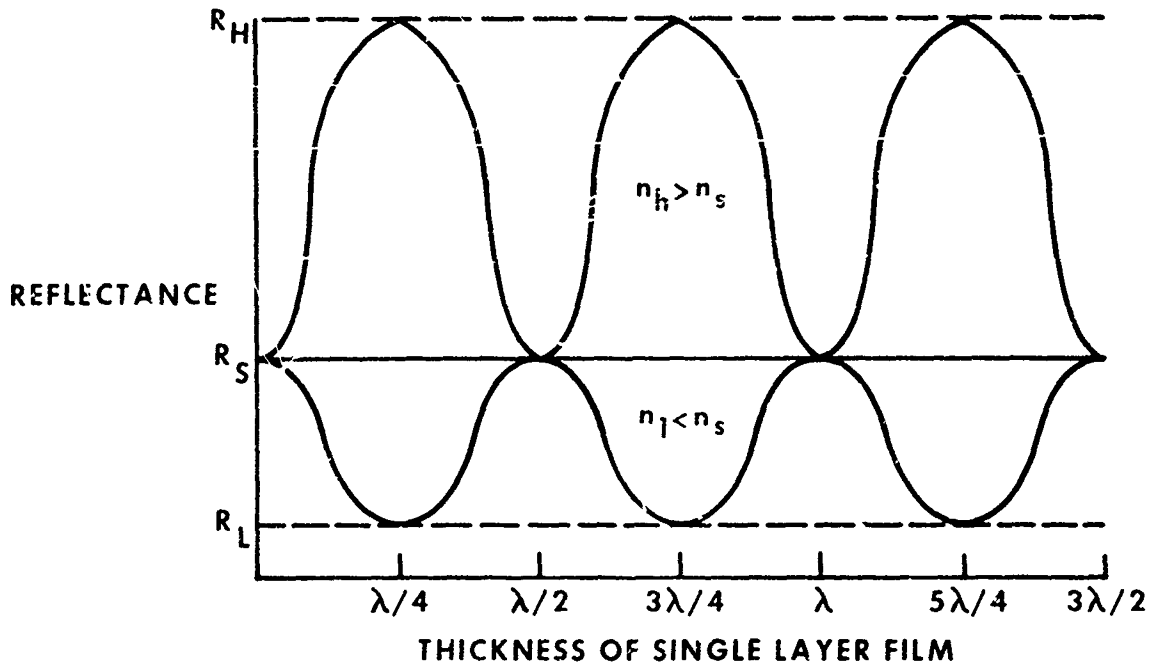

Figure 6. Reflectance as a Function of Thickness of Single Layer.

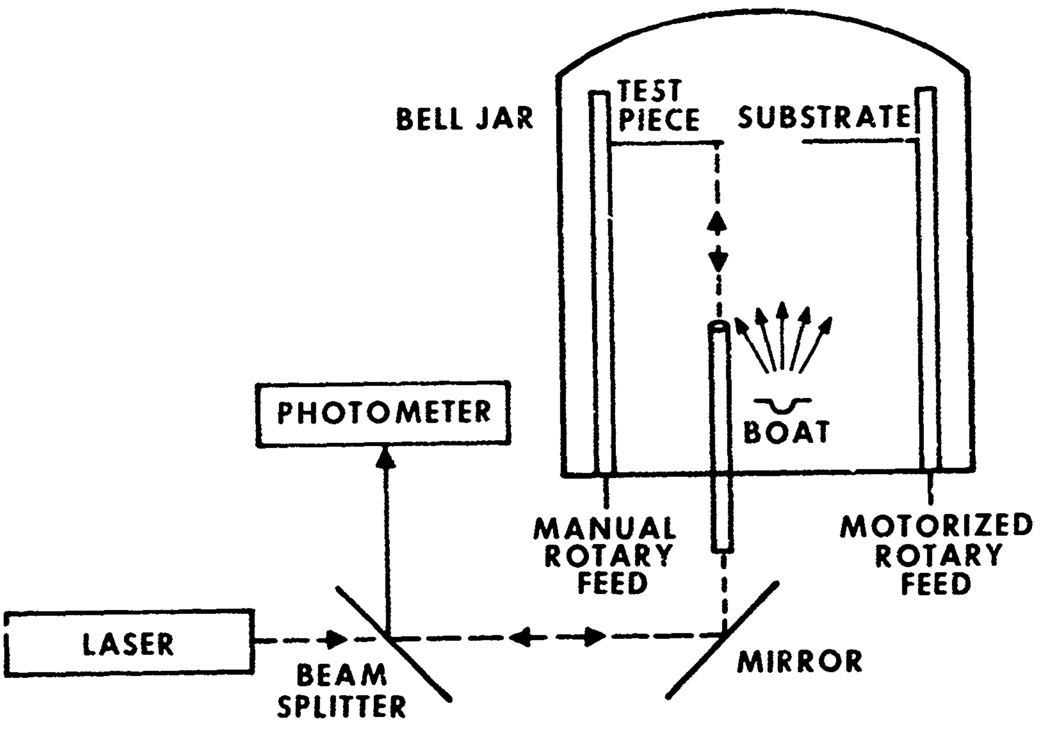

Figure 7. Film Thickness Monitoring System.

140° CLOSE APPROACH OPTICAL PROBE FOR VISUAL SIMULATION

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ABSTRACT

Optical pickups for flight simulators using TV displays have depth of focus limitations at close approaches to the model surface. Tilt focus corrected optical probes have been developed in recent years to overcome this problem while maintaining relatively large entrance pupils. Thus diffraction limitations and lighting problems associated with the pinhole approach are avoided.

A new 140° circular field tilt-focus (Scheimpflug) probe has been developed that can operate to 0.2 inches altitude with an entrance pupil of 1 mm diameter. The single channel device has a 17 mm diameter sensor format.

High resolution levels have been obtained over most of the field and altitude range with a relative aperture of T/10.5. The engineering feasibility model developed has full functional capability using hand-operated controls.

The study and development was performed by the Farrand Optical Co., Inc. New York, under the auspices of the USAF Human Resources Lab., Wright Patterson Air Force Base, Dayton, Ohio

A fully automated model is currently under development.

INTRODUCTION

In the past decade we have seen fairly dramatic improvements in training simulation - particularly in the visual area. The recognition of the value and cost-effectiveness of simulators has paralleled the development of vastly more complex and costly aircraft and space vehicles. A host of recently developed simulation devices such as infinity displays, CCTV and Film image generation systems along with the advances in computer technology now provide a wide array of components for future systems.

The 140° field close approach optical probe is an example of a new basic component tool that will hopefully extend the possibilities of the CCTV-model approach to visual simulation.

USE OF OPTICAL PROBES IN SIMULATORS

An optical probe or pickup is essentially a specialized closed-circuit TV camera lens. As typically used in a visual simulator for flight training, the probe becomes the pilot's eye and airplane. It views the scale model scene and is "flown" over the model at scale speeds and altitudes via its gantry motion capability. (Sometimes, altitude is controlled by model motion while the gantry supplies latitude and longitude). Pitch, roll and yaw are usually provided by the probe itself. Use of a computer controlled miniature prism scanning head allows excellent dynamic response.

Optically, the probe differs from normal lenses in a number of respects, posing a number of unusual design problems. The most serious stems from the requirement that the simulated pilot eyepoint be placed as close to the simulated runway as possible. This is necessary so that reasonably sized models can be employed for fly around and landing simulation. Thus close approach capability is a critical factor in designing a complete simulator facility by allowing more favorable trade-offs between facility and model size (cost) and operating range. A large entrance pupil is also significant here in reducing model lighting complexities and costs.

Of course, close approach capability must be combined with other favorable optical parameters to achieve a successful and economical system: high resolution, wide field of view, low distortion, and a fast relative aperture. The optical system must also be properly mated to the sensor and visual display output so that proper perspective is observed in the complete simulator system.

THE DEPTH OF FOCUS DILEMMA

A normal lens system has its image plane perpendicular to its optical axis. A probe sitting on a model runway has its optical axis (line of sight) parallel to the ground which of course is the plane of most interest. We can focus a normal lens at any distance along the ground but only one vertical plane will be in sharp focus. Distances on the ground will go out of focus as a function of the depth of focus of the optical system. Although stopping down lenses or using pinhole lenses could provide a large depth of focus at the expense of model lighting and sensor sensitivity problems, resolution must be limited by diffraction effects of the small aperture.

A realistic illustration of the problem might be as follows:

For a 1000:1 scale model, a 20 foot pilot height off the runway would place the probe pupil 6 mm off the model. Let's compare the resolution of "perfect" optical systems of 1 mm and 0.1 mm pupil diameters respectively, viewing a point on the horizon and a point 30° down in the field (35 feet ahead of the pilot). The 1 mm pupil system would resolve 2 arc minutes at the horizon but the poor depth of focus would result in a 6° image smear at the 30° point. The 0.1 mm pupil would reduce this to 36 arc minutes, but due to diffraction limitations, the best resolution anywhere in the field, even at the horizon, would only be 25 minutes. We would also be penalized by a hundred fold loss of brightness compared to the 1 mm system. Trade off choices between the two examples are not very promising either.

TILT FOCUS CORRECTION IN OPTICAL PROBES

Until the employment of the tilt focus correction or "Scheimpflug" technique, it was not possible for a probe to obtain a close approach on the order of 1/4 inch along with a "large" entrance pupil (1 mm) and high resolution (6 arc minutes) over a large field. The parameters appeared to be mutually exclusive.

The tilt-focus or Scheimpflug technique works in the following fashion: The out of focus 6° smear described in the example results from the severe image plane tilt when the probe line of sight is parallel to the object plane which in

this case is the ground. This tilted image plane at the probe objective (the equivalent of a small camera lens) varies with the probe's altitude, going from zero tilt to perhaps 45° at touchdown in a typical case. Incidentally, it does not appear practical to place our camera sensor at this variably tilted image plane for a number of reasons including variable field compression, lack of roll capability and dynamic problems. However, a relay lens behind the objective can be used to correct the image tilt by employing the Scheimpflug technique as follows: The tilted image plane is properly relayed to a final fixed normal image plane (at the sensor) when the relay lens is tilted so that a normal plane going through its nodal point joins the intersection of the two image planes in space. In practice, the relay lens is usually a well corrected 1:1 flat field design and will tilt at approximately 1/2 of the image tilt produced at the objective image plane.

PROBES USED IN THE LUNAR MODULE TRAINING PROGRAM

About 6 years ago, the Farrand Optical Co., Inc. designed and built a series of visual simulators for astronaut training as part of the Lunar Module Mission Simulator. Scheimpflug principle probes were employed to obtain a realistic simulation of the lunar landing sequence. Movies taken through this simulator were used during television coverage of the Apollo 15 flight.

The probes had 1 mm entrance pupils and 110° total fields and operated to within 1/2" of a scale lunar model. A 1" vidicon camera system was used to transmit the field to special CRT's and infinity display systems surrounding the LEM cabin. Pitch, roll and yaw capability was incorporated in the probe mechanism. A gantry supplied latitude and longitude motions while the lunar model moved vertically to supply the altitude range.

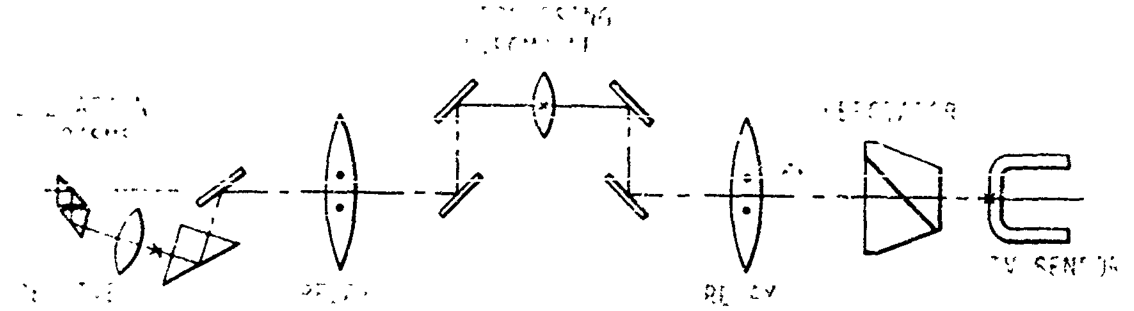
140° OPTICAL PROBE

a. OPTICAL PRINCIPLES

In 1968 the Air Force Human Resources Lab initiated the development of a new tilt corrected probe which while based on previous experience and principles sought to extend the state-of-the-art in a number of areas. The program involved a study phase and a design and hardware phase which resulted in the engineering feasibility probe model shown in figure 1.

A primary purpose of the program was to achieve a gross increase in the field of view with 140° set as a goal. Close approach and large entrance pupil capability were also considered important in achieving a practical system. The unit was to be designed for later updating in several respects:

1. Hand operation could be updated to servo controlled operation.
2. Relay lenses could be added to provide either:
   (a) multiple outputs for better sensor resolution
   (b) multiple outputs for color TV use
   (c) change format size and mapping characteristics for mating with different sensors and display systems.



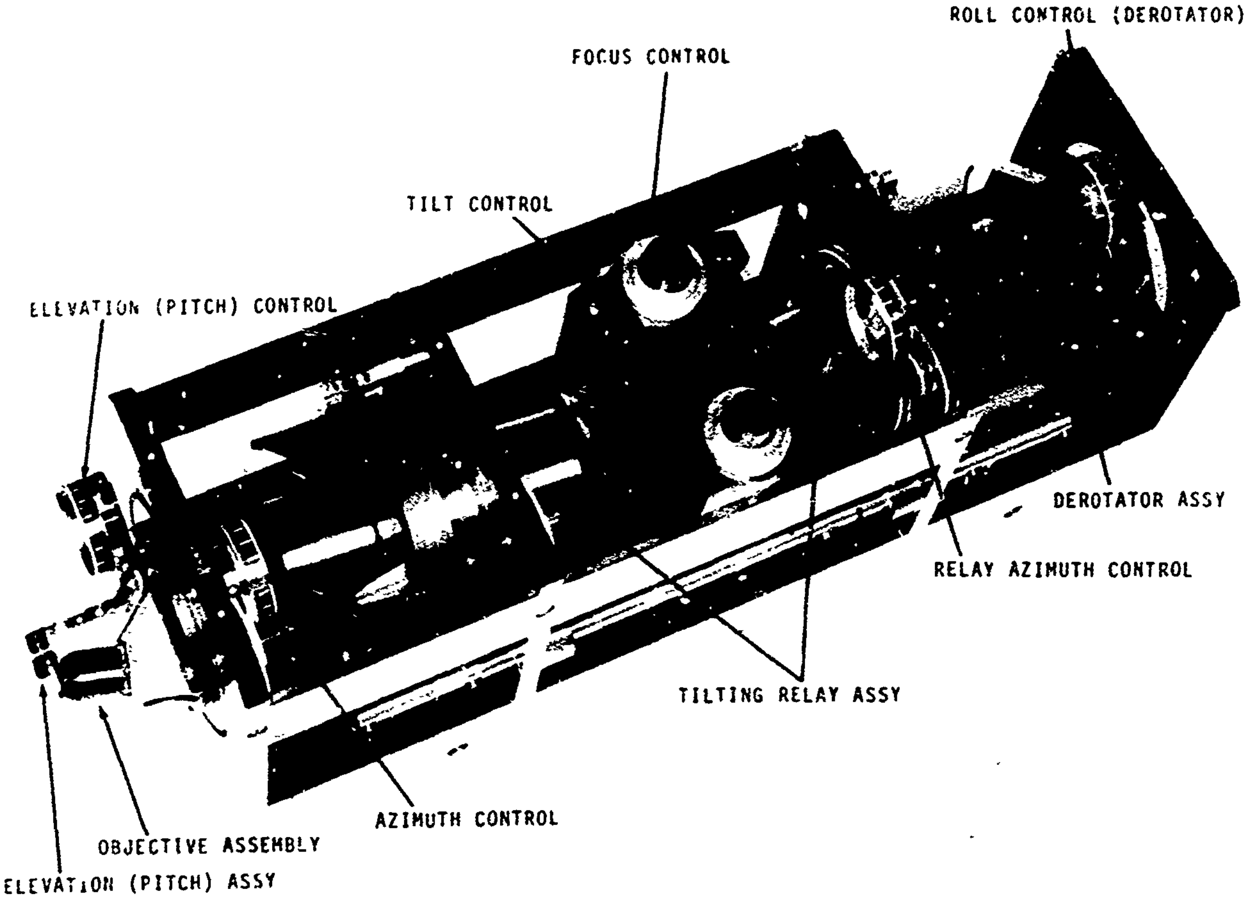


Figure 1. 140° Probe - Engineering Feasibility Model

The engineering feasibility model developed has the following characteristics:

EFL: 6.5 mm
Pupil: 1 mm diameter
FOV: 140° circular
F/no: f/6.5
Mapping: h= Fθ (approximately linear)
Format: 17 mm dia. = 140°
Close approach: 5 mm

Considerable cooperative technical efforts were brought to bear throughout the development. Even in the conceptual stages of the optical design, the mechanical, optical and electrical engineering departments were in close touch so that the resultant device could be made as simple and practical as possible.

In the assembly stages a number of complex alignment instrumentation procedures were employed to achieve the computed design performance in practice.

The model was built and aligned to very close tolerances in order to maximize optical performance and minimize image shifting as a result of component motions. (A lateral image shift of only 4.5 thousandths of an inch could change the line of sight by one degree.) In general, the actual model motion errors were within one thousandth of an inch.

A linear mapping function was chosen because it mates well with a number of infinity display systems and also achieves good illumination uniformity compared to $F \tan \theta$ mapping which would cause serious losses due to the $\cos^4$ law.

The major optical components of the probe are a 140° field objective lens and a pair of 1:1 tilting relay lenses.

The objective lens is an approximately telecentric design with the external entrance pupil located between the prisms used for pitch control. These prisms are dimensioned to allow a close approach of 5 mm to a model surface.

To maintain the correction levels achieved in the objective at low simulated altitudes, a dual relay system was employed. Each relay operates at 1:1 conjugates and both are tied together mechanically. Field lenses between them serve to image the pupils from one to the other. As each lens tilts to achieve the tilt focus correction, the conjugates increase in length. This increase in optical path is taken up by the focus control which adjusts a trombone arrangement of mirrors. The final image plane is thus fixed in space regardless of the relay tilt. A derotator assembly is located ahead of the final image plane.

b. MECHANICAL IMPLEMENTATION

A number of component motions are employed to allow proper focus operation as well as proper functional operation (pitch, roll and yaw). All controls are hand operated but are designed for updating for servo control.

The assembly containing the objective and scan system has an independent rotation capability and an independent elevation (pitch) prism assembly. Both relay lenses tilt together and also rotate together as an independent assembly. A focus control operates a "trombone" slide mirror arrangement. The derotator assembly also moves independently.

c. FUNCTIONAL OPERATION

(Pitch, roll, yaw, altitude)

Pitch is controlled by the elevation assembly and has a range of +60°, -120° relative to the horizon.

Because pitch motion causes a 1:1 image rotation, the relays must rotate to maintain the correct tilt orientation while the derotator is rotated to keep the image orientation.

Roll is operated independently and is continuous.

Yaw requires the synchronous rotation of the objective, relay and derotator assemblies and is also continuous.

Altitude changes are effected by the relay tilt control and the focus control and vary from ∞ down to 5 mm altitude.

d. MEASURED PERFORMANCE

Resolution tests were made across the field and at the center of the field with relay tilt.

RESOLUTION ACROSS THE FIELD AT INFINITY ALTITUDE

SEMI FIELD ANGLE	ANGULAR RESOLUTION	LINEAR RESOLUTION
0°	3'	200 LP/mm
50°	4'	150 LP/mm
65°	7'	75 LP/mm

RESOLUTION AT THE CENTER OF THE FIELD VS. ALTITUDE

ALTITUDE	ANGULAR RESOLUTION	LINEAR RESOLUTION
∞ -35mm	3'	200 LP/mm
15mm	5'	100 LP/mm
6mm	7'	75 LP/mm

On axis contrast transfer measurements were as follows:

25 LP/mm	80%
50 LP/mm	60%
100 LP/mm	35%
150 LP/mm	20%

The transmission was measured as 35%, therefore the T/no. is approximately 10.5.

e. PHOTOGRAPHIC EVALUATION PROGRAM

More significant perhaps than measured performance is the attempt to demonstrate the usefulness of the techniques developed by direct photography of runway models. A 3:1 magnifying relay was attached to allow the convenience of using a single lens reflex camera body, although this limited the horizontal field of the photos to 96°.

Figure 2 shows the model runway with the probe at the minimum look point of 5 mm. The tilt correction was purposely not applied to illustrate the normal depth of focus problem.

Figure 3 is a similar picture with the tilt correction applied. The smallest pattern shown on the resolution chart sitting on the runway represents 10 minutes of arc per line pair.

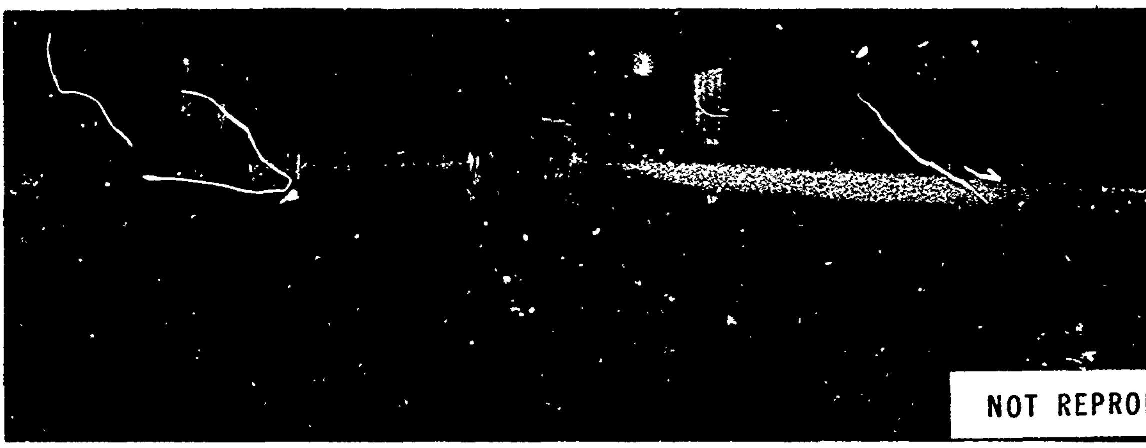


Figure 2. View through Probe Without Tilt Correction

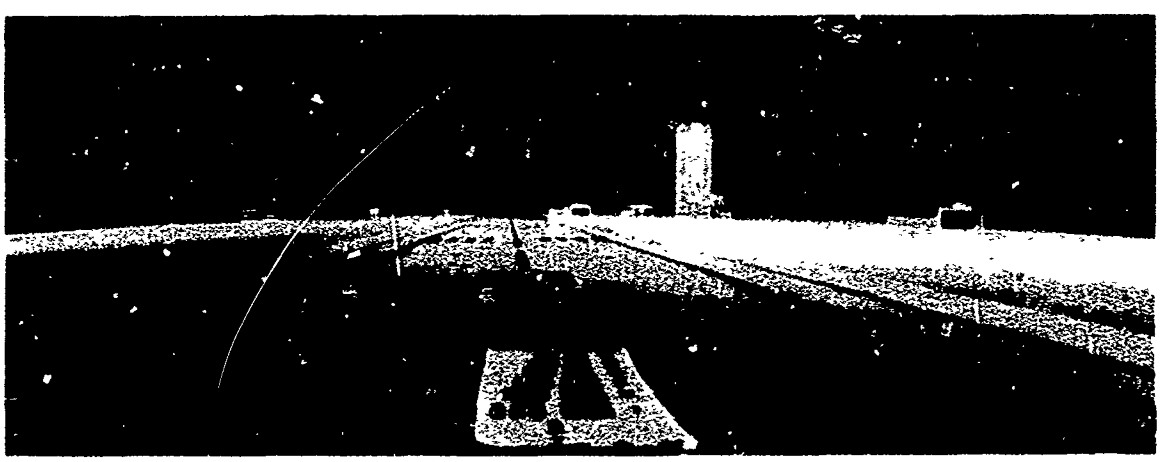


Figure 3. View through Probe Using Tilt Correction

In Figure 4 a penny was placed on the runway to illustrate the scale of the model and the possibilities of a closer approach since the top surface is about .140" from the entrance pupil.

CONCLUSIONS

The realization of this development came about through the concerted effort of a number of individuals and a variety of disciplines. Design goal specifications were chosen effectively for example, so that an advance in the state-of-the-art was realistically possible. Flexibility, as well as close cooperation between the government agency and the contractor also helped immeasurably.

Similarly, optical tolerances in manufacture and assembly were critical in achieving the near diffraction limited optical performance on axis. Individual lens spacers were tailored to measured lens thicknesses and glass index variations.

The engineering feasibility model appears to have enough performance and flexibility to aid in determining where the next significant steps are needed in TV display flight simulators. Will we need even wider fields, closer approaches, more detailed models, more TV sensitivity and resolution, or further advances in optical probes?

Perhaps when the automated version of this probe currently under development is integrated into a complete operating simulation system, the directions for further advances will be clearer.

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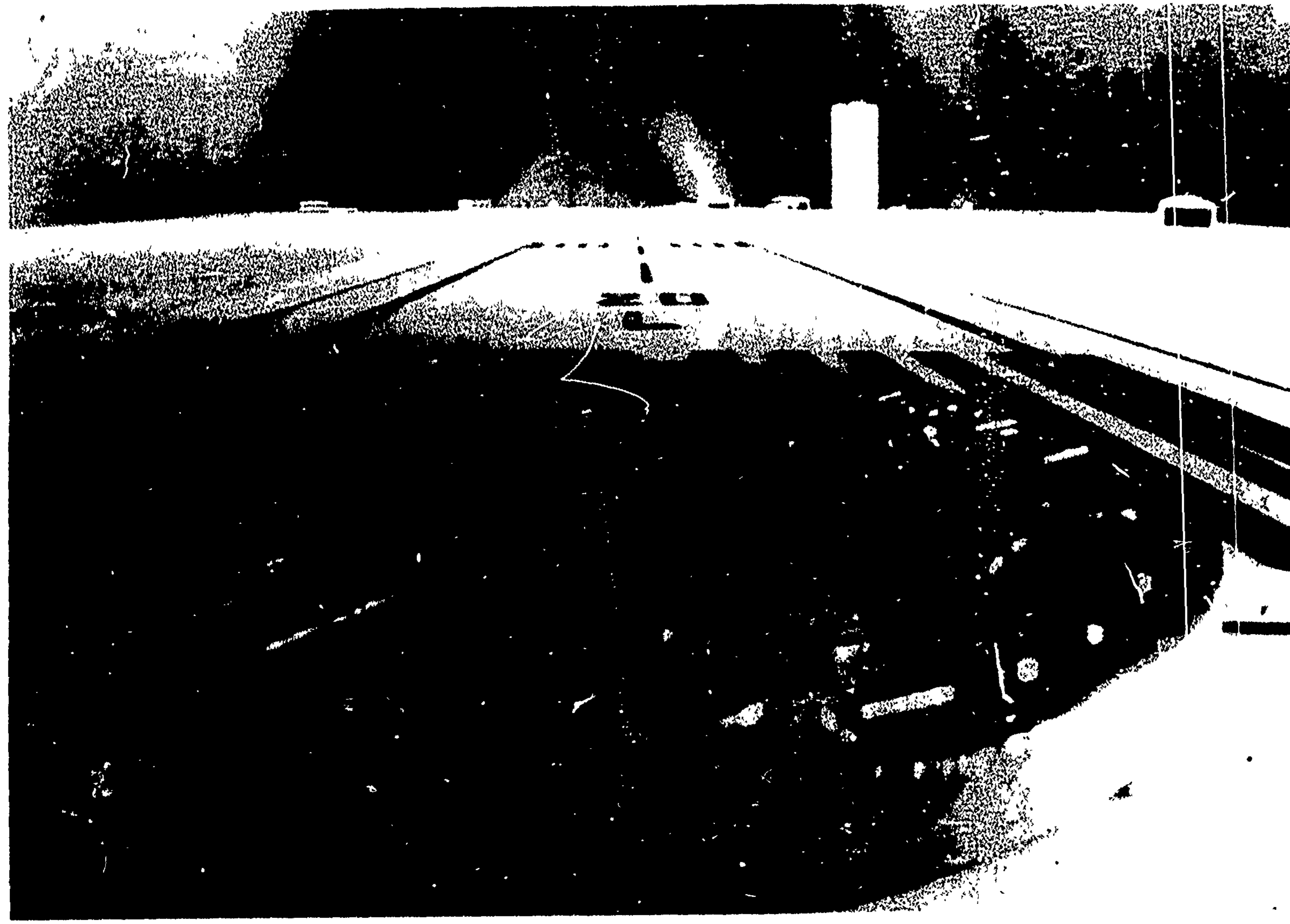

Figure 4. View through Probe of a Penny on Model Runway

A NEW ASSESSMENT OF WIDE-ANGLE VISUAL SIMULATION TECHNIQUFS

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INTRODUCTION

Though two flight simulation techniques conferences took place in 1970 (the AIAA at Cape Canaveral, Florida in March and the RAeS at London, England in October), no objective appraisal of wide-angle visual simulation techniques was presented. William Ebeling provided a brief examination of narrow field of view visual systems at the Second Naval Training Device Center and Industry Conferece in 1967[1] and at an AIAA Conference in Los Angeles in March 1968[2]. The AIAA Simulation for Aerospace Flight Conference at Columbus, Ohio in August 1963 produced two extensive assessments of Visual Simulation Techniques, which are still referenced[3], [4]. Since 1963, there has been some research accomplished on wide-angle visual system components, and also acquisition of operating experience in the military services, airlines, and aircraft manufacturing companies with 1962 state-of-the-art narrow angle FOV (Field of View) visual systems. It therefore appears to be the time for another look at the stable of systems available.

STATEMENT OF THE PROBLEM

The question to be answered is: What are the advantages or disadvantages of the various systems and components available now?

ANALYSIS

What are the possible wide-angle visual systems? They are:

1. Motion Pictures
2. CCTV with Physical Image Generation
3. CCTV with Computer-Generated Images
4. Optical Display Projection
5. Hybrid

Only some research and development accomplished on above systems and components since 1962 will be described, due to limits on the length of this paper. In addition to the hardware effort, at least four conceptual design studies have been, or will be published shortly, which attempt to select the best visual system for specific applications, will be considered. Brief descriptions of the systems and components will be first given and then, performance characteristics will be discussed.

1. MOTION PICTURE SYSTEMS. While a wide-angle motion picture system was developed by NAVTRADEVCEN in 1952, and applied in 1956 to aerial flexible gunnery training[5], this approach was not considered for visual simulation until 1966[6]. The latter wide-angle motion picture system consists of a Fairchild 160°H x 60°V projector lens, a Century projector with a 2500 W Xenon illuminator, fast film pulldown and a 12-1/2' radius high gain spherical screen. Seventy millimeter film taken with a Fairchild wide-angle f/4 camera lens on a Mitchell camera provided the image storage. The projector had a continuous film speed range of 4 to 1. The initial application was to supplement target acquisition field test data by means of laboratory simulation of the pilot's visual task.

Preliminary evaluation of this system by NAVTRADEVCEN for training was conducted in June 1970 using Boeing's version of the JTF-2/SANDIA CORPORATION simulation facility, described in reference (7). In the meantime, UCLA has also used another version for highway driving research.

2. CCTV (CLOSED CIRCUIT TELEVISION) WITH PHYSICAL IMAGE GENERATION. These systems can be described as the 3-D/2-D model with TV camera or FSS (Flying Spot Scanner) pickups and Real or Virtual Image Display. Some of the new components developed are:

a. TV camera with pinhole lens and low light level camera tube for wide-angle and great depth of field.[15, 17]

b. Matched wide-angle anamorphic lenses for a single channel TV system using a TV camera and an Eidophor Light Valve Projector.[16]

c. Wide-angle articulated optical probe with Scheimpflug correction.

d. In line infinity display system (Farrand pancake window).[23]

e. Light weight reflective infinity display system.[20]

3. CCTV WITH COMPUTER-GENERATED IMAGES. These systems replace the physical model of the real-world with a mathematical model and logic stored in a computer (mostly digital). The display portion is as before. The image can be a line drawing with no shading, or a TV raster with computer modulated video in monochrome or color. Both approaches have been developed since 1962[27,28], and with the TV raster approach in use for space flight research.

4. OPTICAL DISPLAY PROJECTION. Both diascopic projection (transparency), and epidiascopic (solid models) techniques have been examined during this period. An improved version of the point light source projection system has been assembled at NAVTRADEVCEN for application to fixed wing aircraft landing, cross-country flight, and also for ship handling in a harbor. An epidiascopic system was developed by Dalto for the FAA Academy at Oklahoma City for Control Tower Operator Training and projected three narrow FOV images of solid aircraft models on a circular screen around a control tower mockup. The images were superimposed on slide projection backgrounds of the airport surroundings. More on the first scheme later.

5. HYBRID. An example of a hybrid system is the Differential Maneuvering Simulator at NASA, Langley Research Center. Here a narrow field of view image generated by a 3-D model and TV camera is projected through a gimballed mirror onto a sphere and optically mixed with a low detail wide field of view background image generated by a point light source. Details and uses are contained in reference(22).

With this brief listing of some research on wide-angle visual simulation components completed, an examination of some of the components' or systems' performance is in order.

RESULTS

To better see the relationship of all the components in a visual simulation system, an improved version of my block diagram is presented, figure 1. We will review only the blocks: Image Storage, Image Generation, Display Unit, and

Viewing means. Even within a single block, such as the Image Generation, and the Display Unit, there are multiple components. In most of the subsystems mentioned, they are an optical train and a TV camera, or a TV monitor, or a projection tube, and projection optics. Image Storage also has multiple components, the model, color, shading and lighting. This inter-relationship must be borne in mind at all times because a comparison of individual components can place you on the outer edge of a tree limb while you are cutting the limb.

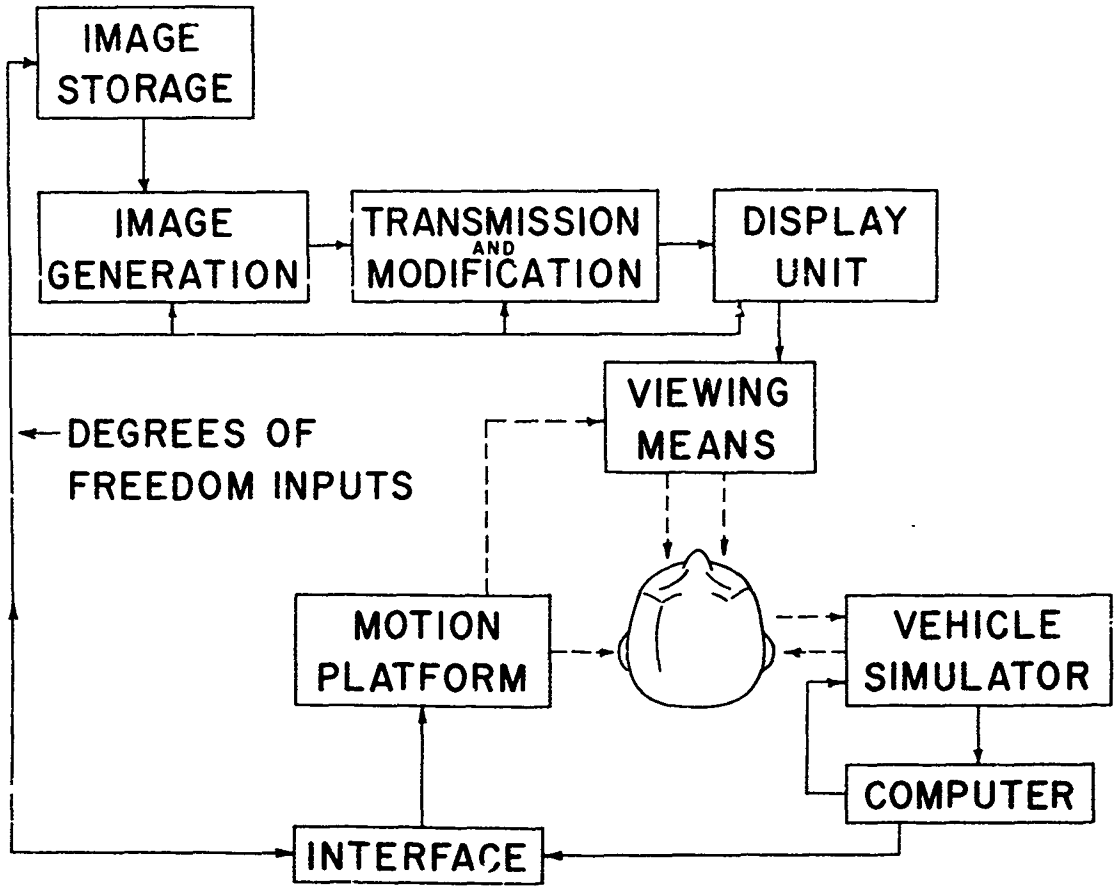

Figure 1. Block Diagram

IMAGE GENERATION. In two studies on wide-angle optics, Goodyear[8,9] identified three critical system design factors for optical probes in image generation subsystems. They are considered here as system parameters, not component parameters.

1. Depth of field or preferably the variation in optical resolution with near distance to object.

2. Working distance or the minimum distance between the entrance pupil and the model terrain.

3. The field of view both horizontal and vertical.

The depth of field characteristics are related to the human visual performance factors of:

a. Egocentric distance localization—that is the ability to judge absolute distance from observer.

b. Depth perception—the feeling that objects are not near you.

c. Depth discrimination—the determination of the relative distance of two objects from the observer.

The criticisms pilots have made of various approach and landing visual simulators may be due to deficiencies in the depth of field of the optical probe in addition to the system limiting resolution.

The depth of field mathematically is defined by the circle of confusion or the limiting resolution in the image plane, the distance from the focus plane to the lens, the focal length and the relative aperature.

Examination of figure 2 will show the difference between specifying a single number for the depth of field and the presentation of resolution as a function of range in the near field. Incidently, in the real-world of typical operating tasks, the ratio of object to image distance using the eyeball may be at a minimum of 400:1, however, with most image generation subsystems, it is about 40:1 or 1/10 real-world and here's where the problems lie.

The figure shows the performance, measured in-house, of some NAVTRADEVCEN devices having wide-angles, as well as other probes and a typical airline visual attachment for flight simulators (Redifon at NASA, Ames Research Center). The horizontal resolution values are system performance observed at the display unit for most systems, but the only independent variable is the object to lens distance. The object in this case was the USAF high resolution test target. Examination of the curve can answer for a specific optical probe what scale should be used for the model to match average trainee and atmospheric visual acuity requirements. Dust[10] described how pilot opinion of the resolution on their visual simulator improved when the model scale was reduced from 1200:1 to 600:1, however, this was at the expense of reduced approach distances as he did not increase the size of his model.

The vertical resolution can be improved by use of the Scheimflug principle in the optical train[8,9], as shown by a comparison of a curve marked "Farrand Tilt Lens," with that for the other Farrand probe. If the object plane (terrain) contains all the items to be used as visual cues, this becomes an acceptable solution. However, when the objects normal to an inclined imaginary object plane, used to provide some improvement, must be in focus and loom across the vertical field of view, this method also suffers a reduction in resolution. At this point, a pinhole becomes an attractive solution. The pinhole has a flatter increase in subtended angle of resolution with reduction in range. It can give a wide field of view and is distortionless. Use of a low light level camera tube compensates for the small aperature restriction and the faceplate light level[15,17]. You will note that each visual simulation combination has a different shape for the resolution vs distance curve, thus permitting optimization at different ranges depending on mission. If the same scale factor was applied to all the systems shown, the point light source system would be superior for target acquisition, low altitude visual navigation and other visual tasks at long ranges whereas the 46° Redifon or the 160° Willey/NTDC lens system would give good performance for approach and landing and the Dalto Pinhole for land vehicle driving where extreme close ranges are needed. But don't make your selection yet as we have only discussed one design parameter so far.

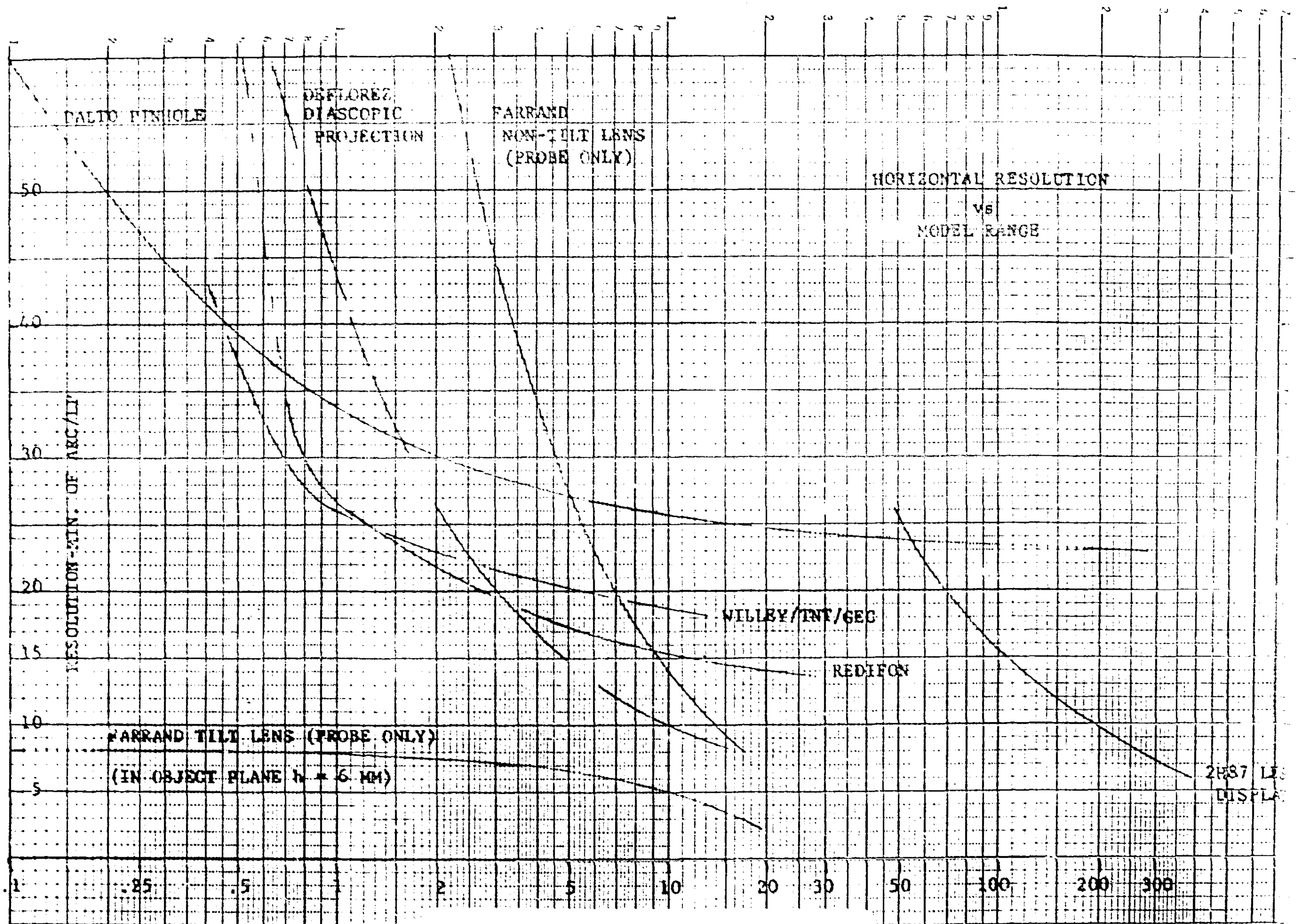

Figure 2. Lens to Object Distance - Inches

TABLE 1. IMAGE GENERATION

A. Optical Probe/TV Camera

Manufacturer	FOV,deg H V	No. of Channels	Distance Pupil to Model,mm	Aperature mm	f/No.	Camera Tube	Reference
Goodyear	210 60	3	5.0	-	6 (S)	-	NAS 8-20686
Willey	180 60	1	44.5	.91 x 1.19	5.6	1" Vidicon	16
GPL/NTDC	160 53	3	44.5	1.7 3.5	5.6 cent. 2.8 side	1" Vidicon	14,24
Farrand	140 Diag.	1	5.0	1.0	6.6 (S)	1" Vidicon	Comp. Brochure
Farrand	110 Diag.	1	6.3	1.0	5.0 (S)	1" Vidicon	Comp. Brochure
Dalto	100 84	1	45.7	.16	84.0	3" Isocon	17
Scanoptics	95 Diag.	1	12.7	1.3	8.0	1" Vidicon	8
Link AVST(1)	90 30	1	9.7	1.2	11-2/3(S)	1½"Vidicon	21
Goodyear	80 60	1	9.9	4	16	1" Vidicon	Dev. 2H87
Goodyear	80 Diag.	1	-	2.5	6(S)	1" Vidicon	18
Redifon	48 35	1	4.3	.93	18	3" Plumb·con	10, 13
			B. Diascopic Projection				
DeFlorez	220 90	1	5.0	7.0		-	11,12

(S) Scheimflug Correction
(1) Proposed Design

Let's look at the next factor mentioned—minimum working distance. This factor represents the pilot's eye when the aircraft is on the ground, the boat coxswain's eye above water level or the driver's eye above the ground. Table 1 lists the characteristics for a number of wide-angle optical probes including those in figure 2, such as field of view, working distance, aperature, f/no and the sensor or the light to electrical energy conversion unit. Working distances of 4 to 6mm for the entrance pupil are obtained by offset optical axes and inclusion of movable prisms and mirrors to provide angular degrees of freedom. The Willey lens is a straight optical axis design and would require rotation of the entire camera by means of a gimbal system to provide the angular degrees of freedom. The minimum working distance can also establish the model scale as it represents the minimum eye distance above terrain required. For example, for an eye height of 10', a field of view of 160° and a minimum resolution of 8 min. at 3000', the proposed Link AVST system would require a scale of 312:1. For a scale range of 9.7' (116") and minimum resolution of 8 min., the only system meeting this requirement from figure 2 would be the point light source. However, if the same resolution was required at 60' (2.3" scale) then no system would satisfy. Examination of figure 2 shows that the point light source would just meet the 8 min. resolution at 16" scale range. The corresponding scale for 60' full scale would be 45:1.

A transparency size of 6' x 6' for the point light source would give a maneuver area of only 180' x 180'. The net result of this numerical exercise shows that there is still a need to compromise one or more of the stated requirements based on the current state-of-the-art.

The last design factor listed above was field of view. This is dictated by the mission requirements[4], however, compromises in the past were made such as accepting a 48° horizontal field of view for an aircraft approach and landing visual scene at a higher resolution at close range and a reasonable size terrain model. As seen from table 1, wide fields can be obtained with either multiple or single channels. The NAVTRADEVCEN destroyer docking visual display uses the GPL/NTDC system and necessitates a terrain model scale of 100:1 based mainly on the minimum working distance for the entrance pupil. When complexity and maintainability are also considered, a single channel TV system or the diascopic projection become prime candidates for larger than 140° horizontal field of view image generation elements. One additional system factor must be considered, that is, the mapping characteristics of both the pickup and projection lenses. To reduce the electronic circuit complexity in the TV camera, the pickup lens and the projection lens must have identical mapping characteristics and cancelling distortion characteristics. Farrand, Fairchild and Willey use the F-θ characteristics, where the height in the image plane h, is given by $h = F.\theta$ (F = Focal length and θ the semi-field angle). This gives more uniform illumination across the face of the camera tube than the F - tan θ mapping which results in the $\cos^4 \theta$ fall-off. In the Dalto pinhole camera, its extreme simplicity did create $\cos^4 \theta$ fall-off, and required an automatic gain control circuit in the TV camera to give fairly uniform relative illumination. Another solution is to add a relay lens after the probe objective to minimize distortion at the camera faceplate (image planes). As far as is known, only the Fairchild motion camera and projector lens set and the Willey wide-angle TV lenses are matched sets.

It seems that this discussion is leading to the other major component I want to cover, the display and viewing units.

DISPLAY AND VIEWING UNITS

As I define it, the display unit consists of the conversion element in the system. In CCTV, the electronic signals are converted to a visual scene by an electronic beam bombarding a phosphor or an oil film. The display unit may be viewed directly, or through an optical train or the image may be projected onto a screen. These additional items can be defined as the viewing unit. Table 2 lists a number of recent subsystems for comparison. In addition to the wide-angle and standard TV systems, a motion picture and a diascopic projection system are shown. The resolution and other characteristics are in some cases for the Display and Viewing Subsystem only and represent the contributions of the CRT, its electronics circuits, the optics and screen. Thus, resolution values shown here may be better than the system values shown in figure 2.

Altes and Chu[26] stated the following requirements for a wide-angle display:

"1. The observer should see an image which appears to be at optical infinity.

2. The field of view must be adequate to take care of head motion of a sitting person.

3. The brightness of the image must be five foot-lamberts or more.

4. The image should subtend an angle of 180° in the horizontal plane and 90° in the vertical plane."

The question of adequate resolution was not answered by Altes and Chu and they recommended experimentation to find the relation of resolution to field of view.

TABLE 2. DISPLAY/VIEWING SYSTEMS

A. CRT Type

Manufacturer	FOV(deg) H	FOV(deg) V	Type	Eye Relief (inches) or Throw Dist.	Exit Pupil (inches) H V	Subsystem Horizontal Resolution	Color	Brightness f-L	No. of Channels	Ref.
Goodyear	240	60	Refl. V.I.	60"	12 x 6	22.5 Min/lp	No	4.5	3	Dev. 2H87
Link AVST(1)	210	29	Refl. V.I.	~ 35"	8 x 5.3	7'/lp	Yes	7	5	21
Willey/TNT	180	60	Refr. Proj.	10' Rad.	-	14.4'/lp	No	10	1	16
GPL	160	53	Refr. Proj.	10'Rad.	-	14'/lp @ (3)	No	1	3	25
GE (2)	144	36	Direct View	20"	-	7'/lp (3)	Yes	15	3	I-H Memo
Goodyear	120	45	Refl. V.I.	41"	12 x 8	6'/lp	No	15	2	20
Farrand	90	70	Refl. V.I.	30"	4	13.5'/lp	No	8-10	1	NTDC Head Set
Farrand	84 Diag.		Refl. V.I. Inline	29"	12 x 8	7'/lp (1)	No	3 (1)	1	23,33
Goodyear	50	41	Refl. V.I.	32"	12 x 8	6'/lp	No	6	1	19
Redifon	48	36	Refr. Proj.	10'	-	7'/lp (3)	Yes	6	1	13
NASA AMES #1	46	34.5	Refr. V.I.	29.5"	11.3" Dia	13.5'/lp (3)	Yes	15	1	32
NASA AMES #2	40.6	30.4	Refr. V.I.	26.9"	12.91"Dia	5.13'/lp (3)	Yes	20	1	13
B. Motion Picture										
Fairchild	160	60	Refr. Proj.	12½'R	-	3'/lp	Yes	26	1	6
C. Diascopic Projector										
DeFlorez	220	90	Direct	10' Rad	-	60-8'/lp (3)	Yes	.25	1	11,12

(1) Proposed
(2) Computer Generated Image
(3) Total System

Refr. = Refractive
Refl. = Reflective
V.I. = Virtual Image
Proj. = Projection

The factor of field of view is covered first. The first requirement in visual simulation is that objects subtend the same angle at the image generation end as they do at the display end. However, in CCTV, the total field of view at the input does not have to be identical to that at the viewing end. The Goodyear Device 2H87 and proposed Link AVST systems provide wide fields at the display by means of multiple channels. The Device 2H87 has included in the wide field of view picture a 80° field angle high detail scene (the carrier) which can be positioned in any channel. The Farrand 90° NAVTRADEVCEN Headset control, provided a 360° field by rotating the display/viewing unit in response to turning head movements. The Link AVST solution proposes electronic slewing of a 90° image across any of the five monitors. The objective in the three systems, was of course, to maximize the resolution along the line of sight. The Goodyear Device 2H87 assumed that the expected L.O.S. (Line of Sight) from the pilot would always be in the direction of the aircraft carrier. For the proposed Link AVST, the rationale has not been developed since the vehicles to be simulated here will not consider single "targets" to the exclusion of other visual cues. The Farrand solution was completely unprogramed in that the display field of view was always centered on the trainee whichever way he looked in azimuth, by head motion pick off.

The next factor covers the illusion of optical infinity. This stemmed from the requirements for aircraft approach and landing flight trainers. For the tank driver task objects 20' in front of the driver must be in focus and this is considerably less than "infinity." To date, no new experimentation has been performed to either verify or upset the assumption given in Altes and Chu and others in the late 1950's, that an image projected at 10' distance on a screen of sufficiently large field of view and with no connecting structures between the observer and the screen does not give distance cues. The only evaluations reported to date on infinity optics displays versus projected displays are those of Dust(10) and Chase(13). Based on pilots' opinions and performance, the collimated image of about 40-50° field of view, marked NASA AMES Number 2, was better than the projected image marked REDIFON because it was brighter and had more contrast, provided improvement in depth perception and minimized blinking. The depth perception was very strong near the ground such that everything stood out more realistically and could really be analyzed very similar to actual flight. However, the collimated optics actually produced an image plane 10.88' from the pilot's eye, whereas the projected picture had a 10' throw, thus, one may say that it was the means for forming the image rather than the "infinity" location of the image which gave the improvement.

Considering the highlight brightness requirement it would appear that all systems shown, except the GPL three channel, met the five foot-lamberts minimum, and about half achieved 10 foot-lamberts. An in-house evaluation, using the GPL/NTDC three channel yielded favorable comments despite the low light level and subjects were able to complete their tasks (ship docking) in approximately the same time as in the real-world. While the present goal of 10 foot-lamberts, based on equivalency with theater motion picture light levels still stands, values down to one foot-lamberts are usable. Planned experiments with the Diascopic Projection (Point Light Source) described by E. Swiatosz, at lower light levels and in color may finally set an experimental floor to this requirement, while experiments using the 160° Willey lens and Eidophor, described by E. Kashork, will cover the high brightness condition.

With regard to subsystem resolution and since the display CRT is larger than the pickup TV camera tube and the optics operate at a fixed distance — equal or better angular resolution is easier to obtain in the monochromatic

mode. Dust[10] has pointed out a problem with the present shadow-mask color TV CRT's of the dot structure size limiting the resolution in a collimated lens virtual image system. It therefore appears that based on present components, wide-angle color displays will consist of multi-channel 60°-80° CRT's, motion pictures, or the diascopic projection. One final word on display/viewing systems. Besides the techniques listed, thought has been given to the use of lasers and rotating mirror systems to generate high resolution and wide-angle displays, though no complete system has been developed.[29]

DESIGN REQUIREMENTS STUDIES

Another way of checking on the course that wide-angle visual systems are taking is to look at the results of some design studies which are relatively unstructured. These studies generally ask for a description of a visual system, besides other components, to meet a broad spectrum of missions without dictating the solution. For example:

a. To provide visual cues to drivers/operators of an Army tank, an amphibious assault personnel carrier, a hydrofoil ship, and an air cushion vehicle. Link proposed, based on their analysis of the training requirements, a 3-D model and TV camera system with a multi-channel virtual image display.[21] This is identified as Link AVST in tables 1 and 2. In addition to the 3-D model, a 2-D model will be used to generate a picture of the waves, and this is inserted into the land imagery for the seagoing vehicles.

b. To provide visual cues for airplane pilot candidates training research, Link proposed four systems to cover all the flight phases.[30]

1. At station 1 on a T-37 flight simulator a Computer-Generated Image with 240°H x 165°V multiple window TV display for takeoff and landing, formation, airwork, and aerobatics flight.

2. At station 2 on a T-37 flight simulator a point light source image generation of sky and ground displayed on a wrap around screen similar to the F-151 Gunnery Trainer and the DMS for airwork and aerobatics.

3. At station 3 on a T-38 flight simulator a transparency or strip film image generation and wide-angle display or a 180° H x 60°V display for 3-D transparencies for navigation and low level flight.

4. At station 4 on a T-38 flight simulator, a 3-D model and TV camera pickup, and a wide-angle display or a computer-generated image and the wide-angle display for formation flying with another aircraft. If CGI, then takeoff and landing capabilities are added.

c. To provide visual cues in a very flexible system for conducting human factors experiments in the development of training device design across a broad spectrum of missions, the contractor proposed:

1. Stage I. A point light source projection using an orthophotographic transparency and a wrap around screen of 240°H x 165°V. The radius is 10' and available light level would be 1-2 foot-lamberts. The advantages are correct perspective and simplicity of construction and operation— no sophisticated electronic equipment.

2. Stage II. Computer-generated imagery with a full-color multi-channel display 100° x 130°. This would be by TV projection on a screen, or by use of inline reflective virtual image display units on a 15-foot radius.

Fifteen-hundred edges are required to provide three independent images on a background. Vertical resolution to be four arc minutes.

Lastly:

d. To provide visual cues for highway driving research using simulation techniques, UCLA, and General Electric Company proposed a computer-generated image and three channel display unit of 60^{o} x 60^{o} flat screens 15' x 15' in a hexagon plan form.(31) The centers of the screen would be 13' from the subject's eye. The image brightness would be 20 foot-lamberts, using a rear projection screen, and a 3000 lumen Eidophor in color. The minimum resolution would be 3.95 min. of arc. Basic system would be sized for 10 independent coordinate systems. There would be a maximum of 1200 edges, 4 textured surfaces, and 500 point "light" sources in the scene portrayed during each image frame.

CONCLUSIONS

Five different techniques for wide-angle visual systems were described, and some data on four of the techniques was presented. Since none of these are universal or all encompassing as shown by the performance characteristics and the conceptual studies, all techniques must still be considered as active candidates for the near future depending on the visual and operator tasks to be performed and trained in. Where programed scenes are acceptable due to the nature of the operator's task, 160^{o} motion pictures in color are tentatively acceptable. When using CCTV with physical image generation, the characteristics of resolution versus range, minimum working distance and field of view will determine the components. When using computer-generated imagery in CCTV, the number of edges and the number of independent images will govern the size of the digital computer. As far as CCTV displays are concerned, multiple channel units will be required for color display. From a reduced maintenance and simplicity of operation viewpoint, diascopic projection for color and the single channel wide-angle TV using a B&W Eidophor lead the other components. While most of the conclusions given are based on the facts presented, the others are derived from introspections, which anyone knowledgeable in the art can make.

RECOMMENDATIONS

What are my recommendations? In view of the number of prototype components and subsystems developed to date, it is recommended that further experimentation be in the area of applications to specific training problems to obtain quantitative measures for sorting out the better solutions. It should be similar to the work of Dust and Chase on the narrow field of view aircraft approach and landing visual simulators and to a lesser extent on the GPL/NTDC system application to ship docking. As I pointed out before, Messrs Kashork and Swiatosz, whose papers are in these proceedings, will explore the Single Channel Wide-Angle TV and the Diascopic projection techniques within the next year. In addition to these, the pinhole TV will be applied to a specific training problem—tank driving. It is possible that next year's conference will have reports on the measures of acceptance of these new systems.

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SESSION III

Wednesday, 16 February 1972

Chairman: Mr. Edward H. Grace, Jr.
Head, Field Engineering and Support Department
Naval Training Device Center

CONFIGURATION MANAGEMENT
AN ASSET TO TRAINING DEVICE
PRODUCTION AND NAVY SUPPORT

MR. J. J. REGAN
Modification and Maintenance Engineering Department
Naval Training Device Center

INTRODUCTION

CONFIGURATION MANAGEMENT! The terminology in itself is enough to foster apprehension when found to be specified as a proposal requirement. Just what is this requirement that the Office of the Secretary of Defense has labeled: "A COMPLEX, MASSIVE and DETAILED UNDERTAKING"? Is it a revolutionary breakthough in the field of management?

The Navy has defined configuration management as:

> "A DISCIPLINE APPLYING TECHNICAL AND ADMINISTRATIVE DIRECTION AND SURVEILLANCE TO"

1. identify and document the physical characteristics of a configuration item
2. control changes to those characteristics, and
3. record and report change processing and implementation status.

Configuration Management new?! Eli Whitney in the early 1800s introduced techniques for the production of firearms with interchangeable parts. The technique! Identify in detail each part and hold manufacture to that identity. Of course, those were the days when life and weaponry were simpler.

1. No written contracts
2. Communications uncomplicated
3. Costs nearly constant, regardless of change
4. Very few acceptable design variations
5. Minimum documentation
6. Only a few people involved.

Both Government and Industry have practiced and improved the techniques introduced by Mr. Whitney and in a sense we might say, Configuration Management! Humbug! We've had it for years.

Let us examine today as compared to Mr. Whitney's time.

1. Written Contracts
2. Complex communication
3. Costs constantly rising

4. Limitless acceptable design variations

5. Monumental redundant documentation

6. Hundreds of people involved in equipment development.

With such problems, enormities and complexities, the task of management is extensive.

Configuration Management is an attempt to:

1. Simplify the task by reducing the elements involved to their simplest terms;

2. Equip each problem with a convenient handle and display the whole situation so that management can comprehend, analyze, and control it.

The Configuration Management concepts of today are basically what Eli Whitney introduced over a century ago.

1. Configuration Identification - it defines the products, its components and their interfaces

2. Configuration Control - restricts idle change

3. Configuration Status Accounting - provides records of changes that are authorized.

But! it does so in a MODERN, DISCIPLINED manner.

CONFIGURATION MANAGEMENT THROUGHOUT DOD

Credit for reviving interest in and for naming Configuration Management must go to the Air Force. The Air Force developed the first documented configuration management standard, AFSCM 375-1.

At the DOD Technical Documentation Conference in May of 1964, the Army and Navy expressed interest in the Air Force effort, and following the conference, The Office of the Secretary of Defense issued direction for development of uniform configuration management throughout DOD.

Subsequent to the direction of DOD, the following events took place:

1. June 1965: U. S. Army Material Command issued AMCR 11-26, Subject: Configuration Management

2. September 1965: U. S. Navy Material Command issued NAVMATINST 4130.1, Subject: Configuration Management. The basic policy cited was stated as follows:

"Configuration Management shall be applied in accordance with the provisions of this manual to all relevant Navy material items or configuration items (CI's) being newly procured for use by the Department of Defense (DOD). It will also be applied to those Navy material items already in operational use; on these items, case by case decisions shall be made, based on the

availability of resources and the proven need for configuration management improvement. IN ANY CASE, ITS APPLICATION SHALL BE CAREFULLY TAILORED TO BE CONSISTENT WITH THE QUANTITY, SIZE, SCOPE, STAGE OF LIFE CYCLE, NATURE, AND COMPLEXITY OF THE ITEM INVOLVED."

DOD Standards subsequently issued, adding to those, which exist and apply to Configuration Management are:

MIL STD 480 Configuration Control - Engineering Changes, Deviations and Waivers - 30 October 1968.

MIL STD 481 Configuration Control - Engineering Changes, Deviations and Waivers (Short Form) - 30 October 1968.

MIL STD 482 Configuration Status Accounting Data, Elements and Related Features - 19 September 1968.

MIL STD 490 Specification Practices - 30 October 1968.

CONFIGURATION MANAGEMENT DURING DEVELOPMENT

The development of a major training device, as like any such equipment, is a complex web of processes, decisions, and interfaces between all individuals involved. The numbers of discrete elements of development form a myriad of virtually thousands of decisions and a proportionate amount of information flow. The management task of integrating all these elements and their efficient scheduling is a mastery of planning and organization.

Let us mentally picture this planning and organization as a well-oiled machine humming with development, fueled by $, and with a specified time limit of operation. Let us inject the element which can and does occur: "CHANGES" Change occurs in varied scope and at all points of a development interface network.

Now let us picture our well-oiled machine with gross numbers of changes occurring simultaneously and steps being retraced or development processes being recycled to that point where the last decision or interface involved is effected. This is analogous to a feedback function in an amplifier which, if not properly designed or controlled, can cause serious oscillation or instability.

Let us look at some examples of change.

Purchasing: The part called for cannot be delivered; request alternate.

Contracts: The customer wants two more and includes the duflop capability.

Product Engineering: Packaging problem; alternate design required.

Design: Hey, hold that release. We found a better way!

Manufacturing: The machinery can't produce it that way. Is this alternate O.K.?

Supply: Is anybody going to use up these 5,000 gidgets left over from the last job?

Test: Oh! Oh! It doesn't work!!

The effort, cost, and time involved to remanufacture, reorder, redesign, retest, or re (whatever) can be avoided in many cases through the basic configuration management elements of identification, control, and accountability.

CONFIGURATION MANAGEMENT AND NAVY SUPPORT

Intertwined with the complex development of a training device and totally dependent upon the flow of data reflecting the hardware is the development of SUPPORT for the long term use of the equipment. "CHANGE" Decisions made during the development phase regarding or affecting:

Maintainability
Reliability
Support data
Training
Facilities
Personnel
Parts
Support Equipment

have a far reaching effect into the life-cycle costs and availability of a training device.

It is because of this far reaching support impact, and its lack of immediate visibility, that an unconscious apathy tends to exist and, which causes support to be left out of many change decisions.

The major problems faced are;

1. Inaccuracy or lack of support data

2. Nonavailability of parts

3. Stocking, cataloging and managing parts made obsolete by change.

Once in operational use, the majority of these problems lose their visibility, and those that are identified require individual correction through a process which further compounds the problems of high cost and loss of availability. Configuration Management provides the discipline needed to assure that support receives its due consideration with every change decision. Navy devices, regardless of how sophisticated or expertly designed are not effective unless dependably available for use.

CONFIGURATION MANAGEMENT - WILL WORK!

Configuration Management will work — if it is understood, accepted and practiced consistently and habitually by both Government and industry personnel at all skill levels.

Configuration Management will work if there is an insistence on optimum uniform practices regardless of superficial argument of the advantages of shortcuts and innovations.

Configuration Management will work if:

WE DO NOT

1. Underestimate the task of configuration management.

WE DO

2. Establish policies, procedures, and documentation adequate to the identification, control and status determination of material items.

WE DO

3. Have management overview of the complete in-house product management function and documentation flow within engineering groups and between engineering and other functional areas.

WE DO NOT

4. Permit the existence of self governing design groups, each having independent design release authority.

WE DO

5. Have adequate design release and drawing control practices for integrated system design.

WE DO

6. Employ "packaged" configuration control with multiple engineering release capability.

WE DO

7 Establish detailed criteria for design change levels at which system analysis and review are mandatory.

WE DO NOT

8. Allow engineering group by-pass of formal change procedures as a result of lax discipline and control of drawings.

WE DO

9. Establish central configuration control with representation from all internal action organizations.

WE DO

10. Provide adequate documentation of changes during the manufacturing phase.

WE DO

11. Designate an individual responsible for Configuration Management.

CONTRACTUAL PROVISIONS

NAVMAT INSTRUCTION 4130.1 provides direction that appropriate provisions for configuration management shall be included in all contracts for the development, production, modification and maintenance of Navy material items.

These provisions cover the contractor's responsibility for:

1. Development of a Configuration Management Plan that describes the methods and procedures for configuration identification control and status accounting to be used during the contract.
2. Maintaining records of any proposed changes to establish base lines.
3. Maintaining that part of the assigned technical data bank that is required for configuration identification and accounting.
4. Ensuring that all procedures and controls necessary to accomplish configuration management are implemented by his sub-contractors.
5. Change proposal initiation.
6. The preparation of equipment/component configuration listings is considered most important to configuration identification. Such documentation to be subject to appropriate contractor management and control to ensure its validity and suitability.
7. Numbering specification-type documents, engineering drawings and other related data composing configuration identification in accordance with appropriate Military Standards or other requirements documents.
8. Preparation of configuration status accounting records. Such status accounting to be subject to appropriate contractor management and control to ensure its validity and suitability.
9. The conduct of configuration audits.

SUMMARY

1. Configuration Management is not new, but merely a simplification, consolidation and modernization of existing management systems.
2. We live in a day and age of modern sophisticated equipment and our management techniques must parallel that sophistication.
3. Let us together understand, accept, and practice this modern management technique to the end of producing and supporting training equipment in the most effective manner.

THE UNIVERSAL DISPLAY PANEL

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INTRODUCTION

The purpose of this paper is to present the latest technology in the development of backlighted animated display panels. By using new industrial components, the design of animated display panels has produced a new breed of programmable training devices. The new Universal Display Panel provides a programmed animated panel with both flexibility and simplicity of operation, which has not been obtained before. The new Universal Panel actually increases training effectiveness, and provides student participation, at reduced training costs.

The Universal Display Panel is a backlighted vertical panel that can light up any section of an attached illustration (see figure 1). The attached illustration is made to appear to operate by an internal programmer that controls the lights behind the illustration. Almost any illustration can be presented on the face of the panel, such as, electrical, electronic, hydraulic, system block diagrams, and Pert charts. The internal programmer is removable and changeable (see figures 3 and 4). The programmer can be controlled from the device control panel, remote control, from the face of the illustration and from a cassette recorder.

A unique feature of the Universal Panel, is that the training illustration and the device operation program can be developed by the using activity, with minimum effort and cost. Another unique feature, is that the training illustration and device operational program can be changed in less than five minutes. As this device is a preprogrammed operating device, a cassette recorder can be used to control the Universal panel and at the same time provide complete lecture material.

The Universal Panel was conceived and designed at the Naval Training Device Center for the Bureau of Naval Personnel. The first Universal Display Panel is being used by the U.S. Mine Warfare School in Charleston South Carolina. The Mine School is presently using three overlay systems with the Universal Panel. Fifteen additional overlay systems will be delivered to the Mine school in September 1971.

PROBLEMS WITH THE NON-UNIVERSAL DISPLAY PANELS

A typical non-universal backlighted display panel is custom built. The illustration is painted on the permanently attached translucent plastic sheet. The background is painted opaque, and the illustration a transparent color. Behind each section of the illustration, such as, logic block or line segment, a light cell is constructed. Each light cell will have one or more lamps. Near each section of the illustration to be controlled is usually a control switch. This illustrates the specialized construction for each of these non-universal display panels.

The illustration usually represents operation equipment in the form of an electrical, electronic or hydraulic diagram. As the operational equipment is modified, so is the training device illustration in order to keep the training current.

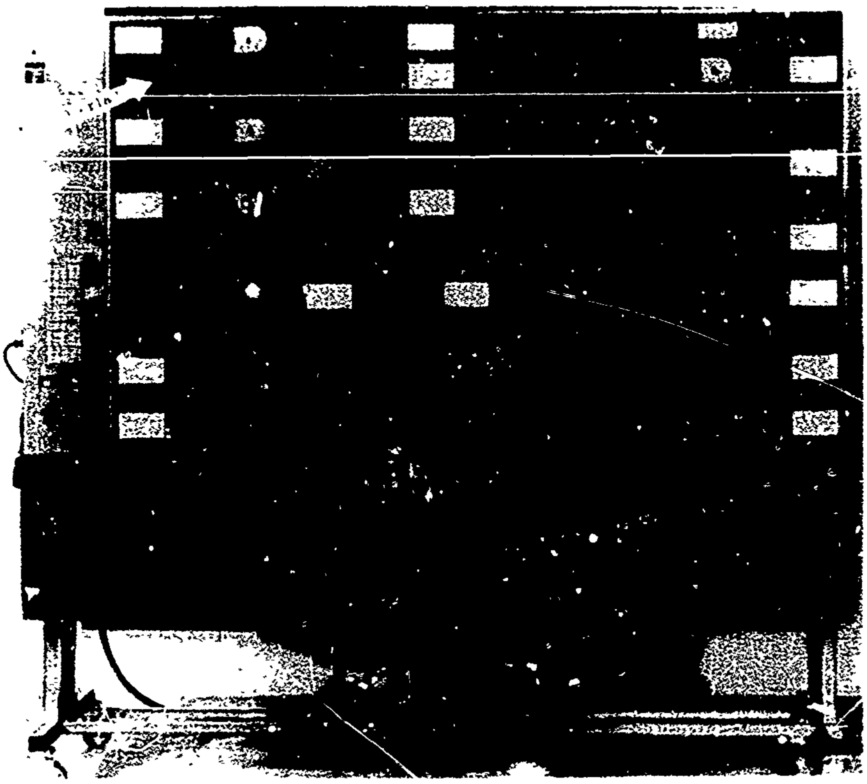

Figure 1. Universal Display Panel with Overlay

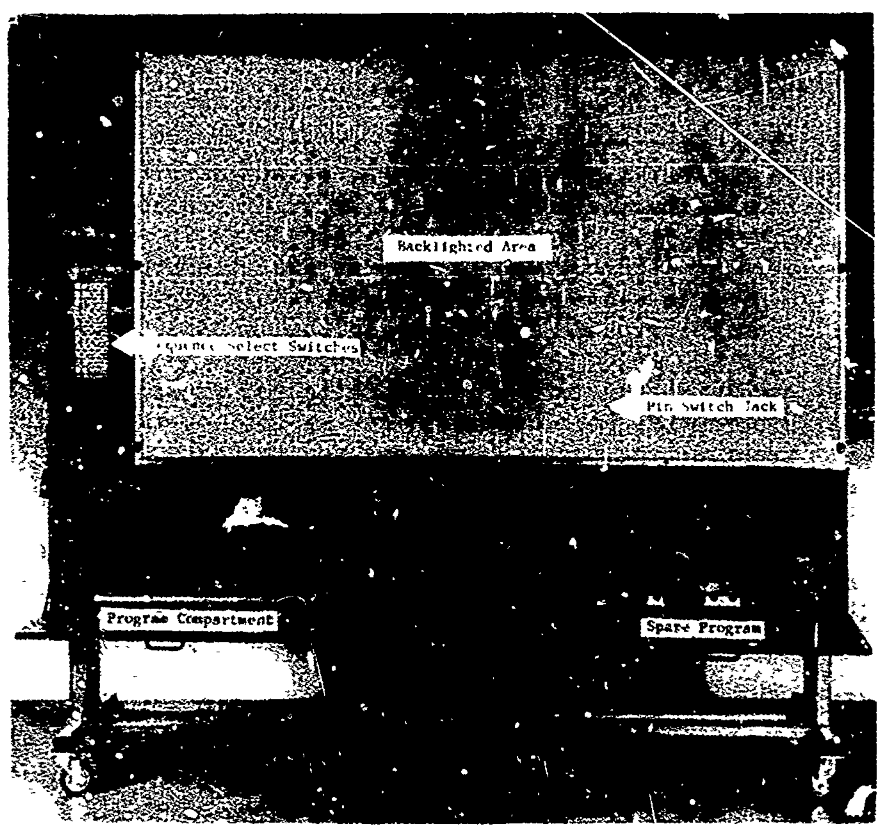

Figure 2. Universal Panel without Overlay

The problems in modifying a custom built device are many. To modify, new lamp cells are added, wiring of lamps and switches added, more power may be required, and the fixed illustration changed. The usual conclusion is that because of the custom fabrication technique, the device is not sufficiently flexible to permit easy and economical incorporation of changes. The end result is a device with a short usage time, and the generation of another device.

DISCUSSION OF THE UNIVERSAL DISPLAY PANEL

The primary design objective was to provide the Bureau of Naval Personnel with a universal backlighted animated display panel that would provide flexibility for changing the displayed illustration, and provide the instructor and student with an automatic programmed presentation. A secondary objective was simplicity in design, operation, programming, and development of illustrated overlays. Simplicity in design, with reliable hardware, provides the user with a device he can understand and will use as intended.

The Universal Display Panel is adjustable in height and provides storage of three overlays. Compartments are provided for the storage of the program system, spare program components, the power supply and spare parts.

The four foot high by seven foot wide backlighted area has 966 two-inch square compartments, with each containing a lamp (see figures 2 and 4). The overlay can contain any type of illustration which can be delineated on a 23 by 42, 2-inch grid scale. The system capability is limited to 118 control grounds and simultaneous operation of 500 lamps, which has proven quite adequate. The programming of these lamps, as required for each overlay, is accomplished by use of a removable patchboard and two removable program drums (see figure 3). The patchboard selects the lamps to be operated, and the program drums activate the selected lamps in accordance with a preprogrammed sequence (see figure 4).

The two removable program drums are used to provide 118 separate switching grounds to control the backlighted area lamps, selected by the patchboard. The program drum system can be stepped to any of 60 preprogrammed training sequences. The removable drum contains movable actuators in order to change the desired program without difficulty. To provide flexible program capability, either one or two program drums may be used simultaneously. This provides either 59 or 118 control grounds for operating the lamps.

The control panel, to the left of the backlighted area, is used to control the operational program for each overlay. For operation, the overlay is attached to the front of the backlighted area and the associated patchboard and program drums are plugged into their receivers in the lower left compartment. By depressing any of the 60 sequence select switches on the control panel, the program drum will step to the selected training sequence and operate the programmed lamps to light up the overlay sections. The program system may also be single stepped to the desired training sequence from the control panel. The illumination of one or a group of lights, as required for progression and continuity of information depicted on the overlay, will then be indicated through the transparent area of the overlay. Flowing lights and blinking lights can be programmed for the overlay. The instructor also has the option to control the programming sequence remotely, from a distance up to 25 feet, using a hand held pendent switch.

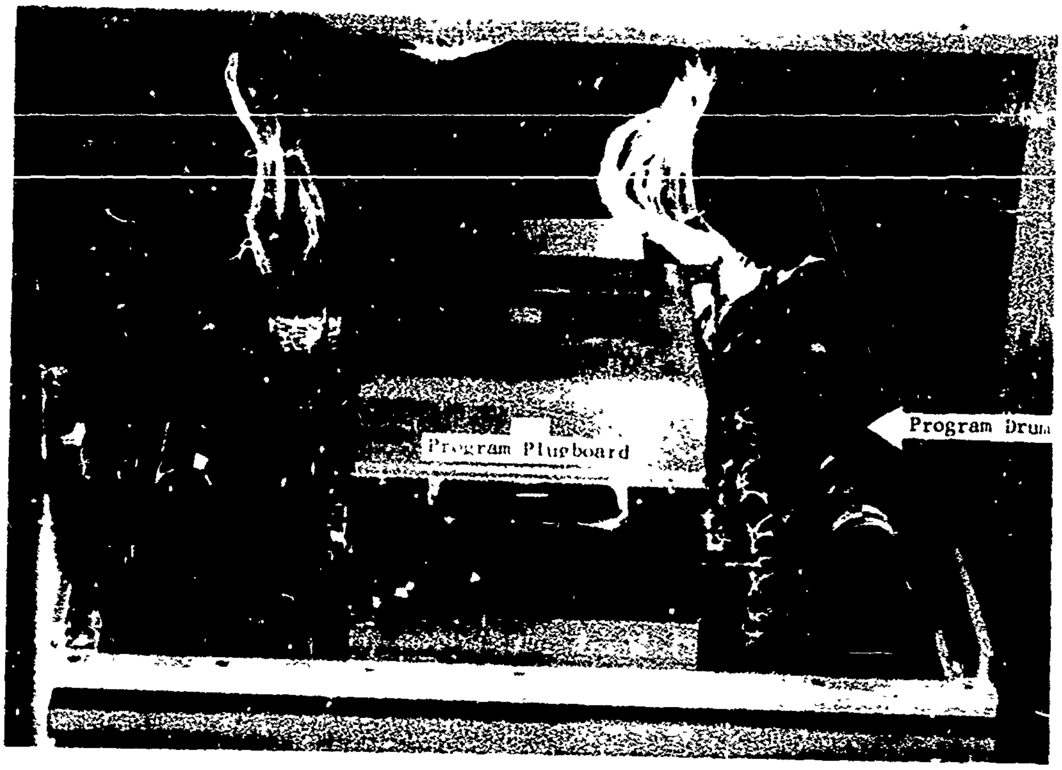

Figure 3. Program Plugboard and Program Drum

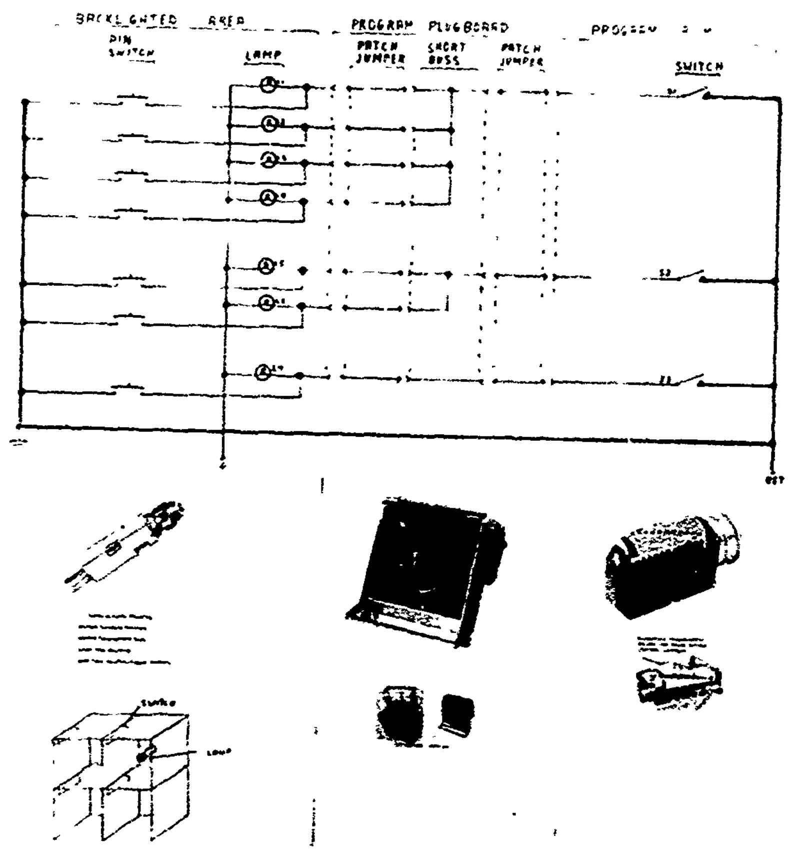

Figure 4. Programming Schematic and Hardware

The device has means for student participation. An open circuit two pole jack is placed in each window of the backlighted area, which will coincide, with a hole in the information area of the overlay (see figure 2). By placing an actuator pin through this hole into the two pole jack, the backlighted area will light (see figure 4). After the operation of the illustrated circuit has been taught, the instructor can have the student repeat the same operation by using the pin control from the face of the overlay. This method provides the important student feedback to the instructor.

The device has means for testing the operation circuits associated with each overlay prior to each training period. By activating sequence number 60 in the control panel, all lamps will light for any given illustration. In addition, a maintenance patchboard and program drum is used to activate all the lamps in the backlighted area to allow periodic testing of all circuits.

DISCUSSION OF THE OVERLAY SYSTEM

The overlay system, Device 3C128 series, consists of a four foot by seven foot transparent or translucent plastic sheet that is 1/8" thick. The illustration is transparent with the background being opaque. Each overlay has associated with it one plugboard and one or two program drums.

The overlay plastic sheets are mounted on the front of Universal Display Panel (See figure 1). The plugboard and program drums are placed in their respective receivers under the backlighted areas of the display panel (see figure 3). The holes, that are located at each backlighted section, allow a shorting pin to penetrate the overlay and mate with the required jack in the Universal Panel.

Any 3C128 overlay system will operate in any 3C127 Universal Display Panel. Thus, only one universal panel is needed per classroom with any number of overlay systems.

ADVANTAGES OF A UNIVERSAL DISPLAY PANEL

Some of the typical comments you will hear, from the user of a typical non-universal animated display panel are as follows:

a. "We don't use the device because it isn't current to our training."
b. "It takes too long to learn how to use the device effectively."
c. "We don't have room in our classrooms for any more display panels."

It becomes clear that training activities desire something better than they now have. The advent of the Universal Display Panel has solved many of these problems.

The advantages of the Universal Display Panel system over the typical non-universal backlighted display panel include the following:

a. Reduce the number of display panels required at a training activity.
b. Reduce the storage area for training devices.
c. Reduce instructor's device learning time.
d. Increase the instructor's training effectiveness by better understanding the device and by faster device operation.

e. Provide student feedback to instructor.
f. Reduce modification cost by permitting the school to modify illustration or make new illustrations and programs.
g. Reduce procurement time and costs per device, illustration and associated program equipment, due to commonality of design.

Specialized Universal Panels have been developed with almost all the advantages of the Universal Panel. For example, a Universal Panel with the addition of the actual equipment control panel. In this case, the backlighted panel will function from either the actual equipment control panel, or from the universal control panel.

CONCLUSION

The use of modern hardware in a unique manner has provided a training device, that can be used in many classrooms, for teaching a wide variety of technical subjects. Progress has been made in reducing training device obsolescence, thus reducing the overall training cost. Further improvements in cost reduction and improved devices are in the system now and will be seen in the classroom within a year.

REAL-TIME PROJECTED DISPLAYS

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INTRODUCTION

There has long been a need for a real-time dynamic projected display for large screen applications involving group viewing. The majority of the present systems utilize a form of slide projection or an oil film light valve. Slide projection makes use of silver film, Kalvar film, or a coated glass slide. These systems provide the brightness required and are near real-time. The film systems suffer from the problems associated with chemical development, film transport, and consumable costs if the system is frequently updated for real-time operation. Coated glass slides are utilized in a system where the image is scribed onto the slide in the projection gate. This provides the capability for continuously updating the current position on a given frame. A new frame must be generated when the viewer wishes to change the display content, for relocation of target tags, and when the historical data grows to the magnitude which tends to confuse rather than aid the viewing audience. Several modulated oil film light valve systems have been developed and are in use. Because of the nature of the modulation mechanism, it is necessary that these systems be operated in a scanned mode, thus limiting their application to those where scan or television type data is readily available, or can be made readily available. Most of the systems operate at a 525 line television standard,

although a few of the older systems have been modified to operate at a 945 line standard. The resolution overall in either case falls in the 400-600 line range. The newer systems have the advantage of a considerably simplified tube not requiring continuous vacuum pumping.

The search for a technique has continued with considerable money being spent, both by government and private industry on the development of techniques which will overcome the shortcomings of the existing systems. Direct projection from a cathode ray tube was abandoned a number of years ago because of inadequate brightness and resolution. However, recent developments in this field have enabled General Dynamics to produce a real time projector which exceeds the capabilities of other systems and fills the needs of a large segment of the industry.

DEVELOPMENT

Late in 1969, General Dynamics undertook the development of a real-time projected display, based upon developments in the area of high brightness CRT's. Prior to this time, CRT's with adequate brightness and resolution were not available for comprehensive data projection. This projector utilizes a very high brightness, high resolution, 5" CRT mounted in a Schmidt optical system.

As a result of this development, equipment was produced and delivered to the Navy in late 1970. Figure 1 is a photograph of that projector. It has been in use in an ASW Tactical Analysis Center, where it presents an 8-foot square image on a rear projection screen. Figure 2 shows the optical system with the covers open. You will note that this is a classical Schmidt optical system. The image on the face of the tube is collected by the spherical mirror and directed towards the screen. A short distance from the mirror, an aspheric corrector plate corrects abberations in the system,and assists in imaging the data onto the screen. The CRT is specifically designed for projection in this type of an optical system. The radius of curvature of the faceplate is carefully chosen as it is a part of the optical system. General Dynamics choose the reflective optical system over a refractive system because of its simplicity, lower cost, larger aperture, and fewer elements. Refractive optical systems are available for projecting data from 5" tubes. These, however, require 9 optical elements with their associated air glass interfaces and precision mounting. These refractive lenses are approximately ½ of the optical speed of the Schmidt system and provide the same resolution.

SYSTEM IMPROVEMENTS

Late in 1970, advances in the state-of-the-CRT art produced an even higher resolution, higher brightness CRT, which we are now using in our projection systems. This CRT, also specifically designed for a reflective optical system, incorporates a ground and polished faceplate,and produces a very high resolution image (spot size .0035 inches) at a brightness level of 20,000 foot-lamberts when operated at 40,000 volts. This tube provides a significant improvement in the brightness and resolution available from the real-time projector.

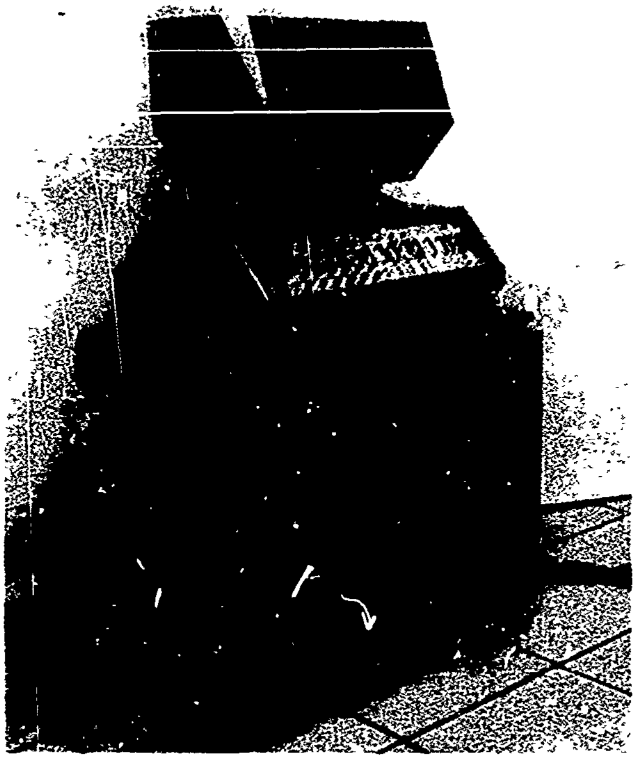

Figure 1. Real-Time Projector

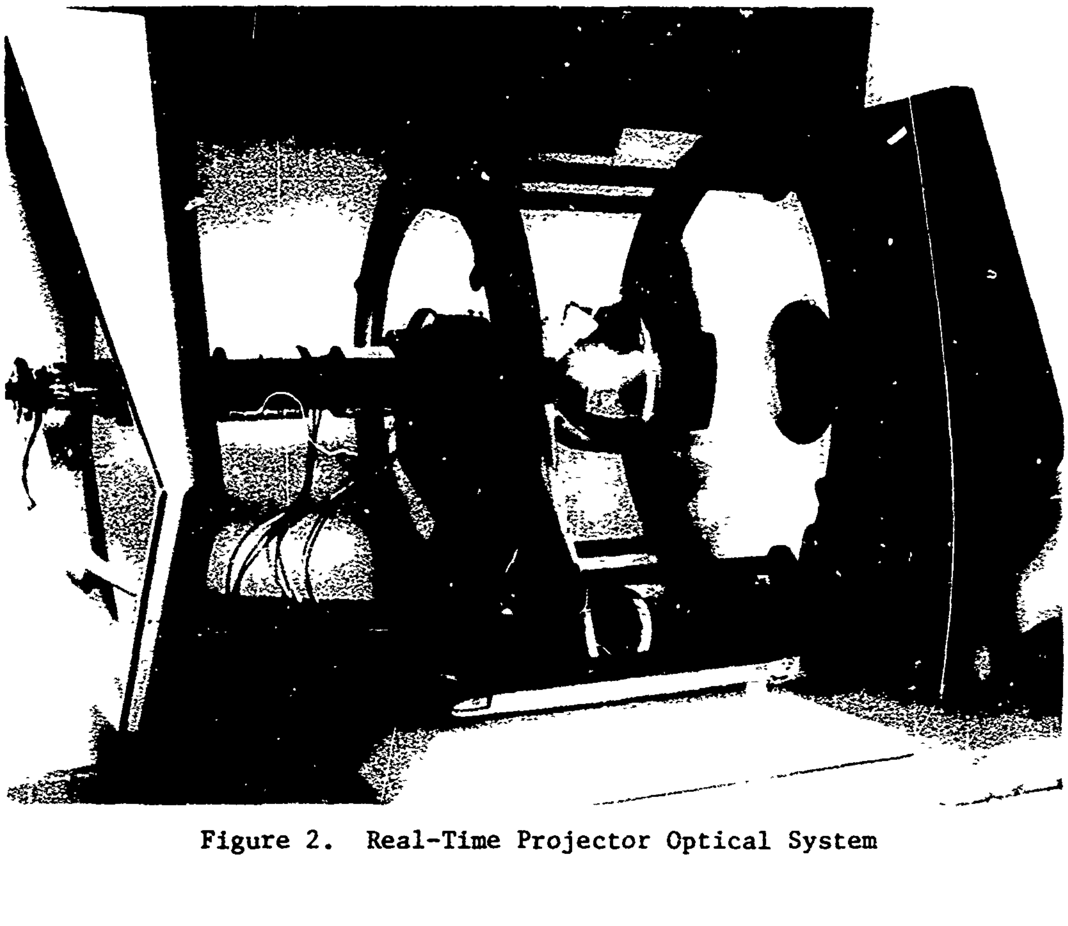

Figure 2. Real-Time Projector Optical System

Figure 3 is a photograph of a 5 x 5-foot air traffic control display on a rear projected screen utilizing the high resolution tube. The entire display is computer-generated, including the background data (range rings, fixes, holding patterns, approach paths, warning areas, obstacles, etc.) This particular display was programmed for two character sizes and two brightness levels. The number of character sizes and brightness levels used are not limited to two, but rather are defined by the system requirements. It is desirable to limit the number of character sizes and brightness levels to four or five each in order that the significance of this coding can be readily interpreted by all viewers.

Figure 3. Projected Air Traffic Control Display

The target (aircraft) symbol and its associated tag shown in the photograph are typical of those used by the FAA in the Atlanta Center. It is obvious that any target symbology or format structure can be utilized. You will notice the clock at the bottom of the frame. This is a real-time clock which runs continuously. A specific symbol is used to identify the aircraft. These are "N" for northern arrival, "W" for a northern departure, and "Z" for southern departure. A box

is used to indicate an aircraft transiting the area neither arriving nor departing from Atlanta. The airline and its flight number are on the first line of the format. The second line contains the altitude in hundreds of feet and the ground speed in knots. The third line is the computer track number and the aircraft's beacon code. Obviously, the formats could contain anything that is useful to the operators. These features could also be suppressed through operator keyboard actions, thus clearing the display when the data is not needed.

The system is a very flexible one and provides the capability to off-center to any given point. In addition to off-centering, there are expansion capabilities. Together these permit the operator to off-center to any point, and expand to any scale. You will note that the background features such as the runways, the extensions, warning area, are all contained in the dynamic data projected from the CRT. This background can be suppressed and the same information presented by projection of background slides. By reducing the amount of static data handled by the dynamic system, additional capability is provided for dynamic data. The overlay of static data by means of projected background slides is readily accomplished. Registration between the slide and the dynamic data is good. There are many slide projectors which provide a large background slide capacity. The standard Carousel has a capacity of 80 slides. Other units built for industrial purposes can extend this number to several hundred with a unit custom designed for a large program having a capacity of 1,000 slides. Background provided by means of slides can be in a contrasting color or in full-color, depending upon the requirements.

In addition to the improvement in the system resulting from advances in the tube art, advances have also been made in the optical system. The optical system shown in figure 2 was developed for television projection, and as such, does not have the edge resolution which is necessary for data presentation. These optics have a resolution of approximately 800 lines in the center and 350 lines at the edge. While this is adequate for entertainment material, it is inadequate for full-screen data presentation. For this reason, General Dynamics has developed an improved optical system. This optical system provides a minimum of 1500 line resolution at 60% modulation over the entire viewing area — a significant improvement. This development is complete and these optics are available for delivery in current systems. An improved set of driving electronics has also been developed. This set of electronics contains approximately 1/3 of the modules contained in the earlier version, further increasing the unit's reliability and decreasing the cost.

EQUIPMENT DESCRIPTION

Figure 4 is a block diagram of the equipment. The timing and control logic sorts the input data, and routes it to the appropriate points. Although, the electronic circuitry is straight-forward and is typical of that used in direct view CRT displays, certain portions deserve additional comment. The character generator, a proprietary item, is a 22-stroke character generator operating at a stroke rate of 8 MHz. This permits the typical alphanumeric character (10 strokes)

to be generated in 1.4 microseconds. Separate deflection yokes are used for main positioning and for character generation. This permits the system to generate characters at this high rate. Vectors and ellipses are generated through the main deflection system. A full-screen vector is written in 40 microseconds. The distortion correction circuit is utilized to eliminate a small amount of pin cushion/barrel distortion which exists in the system when precision registration is desired. The protection circuitry controls the application of high voltage and unblank signals to the tube, thus preventing tube operation unless the proper deflection and power supply voltages are available. This safety feature prevents inadvertent burning of the phosphor.

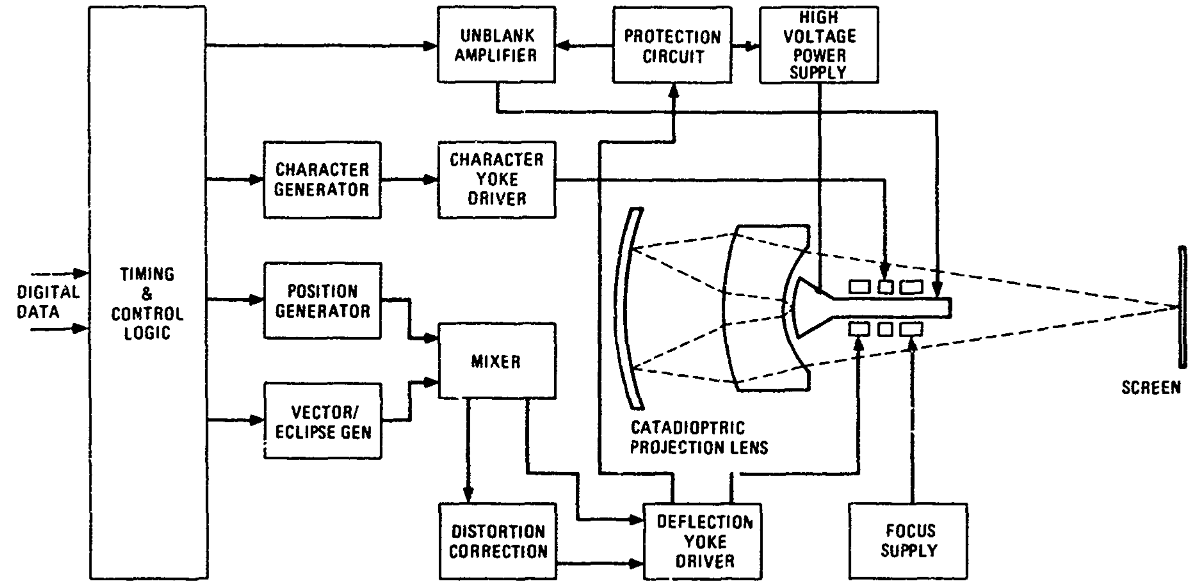

Figure 4. Real-Time Projector Block Diagram

You will note that the catadioptric projection lens is similar to the lens shown in figure 2 with certain important differences. A spherical lens element, placed between the tube face, and the mirror replaces the aspheric corrector. This improves the resolution while at the same time because of its location, does not captivate the tube within the optical system. The tube may be removed for maintenance purposes without optical system disassembly. Because the tube operates at 40 kilovolts, precautions are taken to prevent the soft x-rays generated by the beam impact on the phosphor from leaving the enclosure. Measurements confirm that the radiation external to the housing is less than 0.5 milliroentgens per hour. This level has been established by the Federal Government as a safe level for home television receivers.

While we have shown a computer-driven display in the block diagram, the projection system, since it is based upon a CRT, is capable of displaying and being driven from any of the information sources typically used in driving CRT displays. The unit can be readily configured to operate as a high resolution TV projector. It can also operate in a multi-purpose mode in which digital presentation is time-shared with analog signals such as television, scan converted

radar, etc. For monochromatic applications, we have selected a green phosphor because of the sensitivity of the human eye to this color. A multi-color display can easily be generated. The simplest method to achieve this is through the use of multiple projectors with different color phosphor on the different projectors. A system is under development,which utilizes two projectors, one red and one green, displaying on a common screen. Friendly forces would be depicted in green with the hostile forces in red. Penetration phosphor techniques currently under development may produce the capability for multi-color display from a single tube. There are still some hurdles to be overcome in this program before it is a practical system.

The applications of the real-time display are limited only by the imagination of the systems designer. Applications include military command and control systems, tactical data systems, air traffic control, simulation, training, and management information systems. This system provides the highest resolution, real-time projection of display material available today.

The performance features of the real-time projector are summarized below:

Display Size	5' by 5' typical (2' x 2' to 8' x 8' available)
Projection Method	Front or Rear
Throw Distance	10 Feet
Screen Gain	1.5 nominal
Magnification Ratio	20X
Symbol Height	1"
Line Weight	.07"
CRT Diameter	5 3/8"
CRT Phosphor	PT-411 (green)
Accelerating Voltage	40KV
Refresh Rate	60 Hertz
Display Brightness	15 Foot-lamberts
Symbol Generation Time	1.4 microseconds (for average 10-stroke char.)
Vector Writing Time	40 microseconds full screen (proportional to length)
Deflection Settling Time Major Step	10 microseconds
Deflection Settling Time Minor Step	4 microseconds
Optical System	Reflective with f/0.7 aperture 1500 lines resolution with 60% modulation limiting resolution - 3,000 (nominal)
Tube Life	2,000 Hours

SUMMARY

In summary, the large screen real-time projector described is an advanced state-of-the-art equipment. Being a CRT, it can be utilized in all applications where CRT's are used today and it is compatible with the driving requirements of current displays. It can provide to group audiences, those displays and data formerly available only to operators of individual consoles on a real-time basis. It is very flexible in operation and does not limit the system designer to update cycles or history trails which may be undesirable. No chemicals are involved nor is there a continuous consumable requirement. The low cost, long life projection CRT is readily replaceable. This system is without equal for the display of dynamic data in real-time to a group audience.

BUILT-IN TEST (BIT) FOR TRAINING DEVICES

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Aerospace Engineer and Electronic Engineer, Respectively
Naval Training Device Center

As trainer electronics grows in scope and complexity, a similar growth is required in the equipment needed to check it out. The importance of speeding the repair of trainer systems is being accentuated by the increasing complexity of computer systems, microminiaturization, incorporation of operational equipment and GFE, and the demand for realistic, cost-effective training. Many approaches are being investigated, including sophisticated off-line test equipment, built-in test (BIT), and fault-analysis systems that isolate the fault to a single black box. For some applications, automatic test equipments (ATE) are being considered that can be used to isolate the fault within a black box, indicate the needed repair, and check out the required unit for proper operation and adjustment.

Little thought and time were devoted in the past to the design of test and checkout equipment. It is now evident that the same consideration should be given to the design of a test equipment system as we give to the design of the trainer system. A thorough analysis must be made of the training requirement and of the mission of the test system and its environment. Trade-offs must be made between the constraints of cost, time, operator skill levels, accuracy, repeatibility, and user confidence to arrive at an optimum test system.

Since most training devices are unique, or at least limited in number, the justification for using a fully automated test system from the standpoint of cost-effectiveness is questionable. There is justification, however, for utilizing Built-in-Test (BIT) on the more complex trainers and life-critical trainers such as environmental chambers.
Some of the more important factors to consider when deciding to incorporate BIT are:

a. It aids in achieving a more maintainable trainer by reducing the MTTR (mean-time-to-repair), which ultimately results in a higher operational availability factor. The high level of availability (98.5% or higher) required by most using commands is achievable only by using highly reliable equipment supported by efficient test and maintenance concepts.

b. It makes possible the diagnosis of failures in complex systems where manual methods of fault detection and fault isolation are impractical.

c. It reduces the maintenance manpower burden by reducing the overall maintenance man-hour and skill level requirements. The life-cycle cost of assigning three extra Navy TD's (TRADEVMEN) to a training device for 10 years is on the order of a million dollars. In addition to reducing manning requirements and costs, BIT can guarantee a consistent performance capability for failure diagnosis independent of the individuals assigned.

It reduces the requirements for general and standard manual test equipment and the associated requirements for calibration and repair.

e. Easily repeated consistency standard tests can be quickly run and rerun with a minimum personnel effort during engineering test and checkout to certify most of the interval hardware operations.

BIT costs are decided by the level of failure identification desired. With the modular construction techniques used in trainer design today, the most cost-effective repair level is failure identification to an LRU (line-replaceable unit). In most cases the LRU will be a replaceable module such as a printed circuit card, and on occasion the LRU may be a functinal grouping of 2 or 3 cards or a small sub-assembly of a larger assembly. Specific fault isolation to a lower level and the repair/discard decision can best be accomplished off-line at a later time. With this maintenance concept, the trainer will be back on the line quickly with a minimum loss of training time.

Let's take a look at what some contractors have done with BIT for training devices. We'll be looking at various degrees of sophistication, all the way from simple monitoring systems to computer-controlled test programs. Some of the more basic types of BIT are panel meters and indicator lamps. One of the first orders of sophistication would be to add a manual scanning system, which consists of a standard rotary switch connected to selected test points. Even this simple example of BIT can be made elaborate by use of a test point scanner which automatically feeds information to the meters and lamps.

When a failure occurs in a system, one of the initial steps the technician will take is to verify the condition and the very existence of his power. This can be accomplished in a variety of ways, perhaps by using a combination of methods. Is the unit "plugged in"? Is a blown-fuse lamp lighted (basic BIT)? Perhaps the maintenance man has available a Power Supply Status Panel such as that used in Device 2B24. The panel consists of a matrix of lamps which gives instant Go, No-Go confirmation of the condition of the power. A test lamp feature precludes a burned-out bulb giving an erroneous indication. A very simple, yet useful example of BIT.

Most complex training devices already have the necessary equipment to perform extensive testing, particularly those with digital computers.

Another, more complex form of BIT is "introspective testing". "Introspection" is the utilization of one part of a system to test the entire system. Many contractors are now using the main trainer computer for testing in response to the requirements of MIL-T-23991C, General Specification for Military Training Devices. Device 15E22, EA-6B Team Tactics Trainer is a good example of this application. The maintenance and test programs for Device 15E22 consist of a variety of open-loop and closed-loop test routines. These routines not only detect faulty assemblies and modules, but they also indicate the nature of the failure. There are five basic categories of test programs:

a. Test Exercise Program - Checks the accuracy and flow of signals between the computer and all signal sources and terminal points in the trainer. The program is also used to calibrate the interface equipments and all displays and controls, and it is capable of exercising the equipment in both static and dynamic modes.

b. Daily Readiness Check - Determines visually that the trainer is ready for operation. This check uses automatic sequencing through a series of static outputs, utilizing the normal iteration rate of the main simulation program. A provision is also made for stepping through the programs or portions thereof, incrementally to verify the desired outputs. The type and nature of all failures are permanently recorded through the use of a teletypewriter.

c. Computer Diagnostic Programs - Commercially available diagnostic programs are used for the computer system.

d. Real-time Interface Equipment Diagnostics - Enables on-line program control checkout of the simulation interface equipment. These programs are automatic, requiring a minimum of operator intervention, and they provide a hard-copy of the test results. These diagnostics can be further broken down into two subprograms:

(1) Discrete input/output tests - Check the proper functioning of the discrete input/output channels of the trainer in a closed-loop fashion. All disconnection and reconnection are accomplished either under program control or by using a patchboard type device. Upon detection, the program indicates to the operator the faulty channel.

(2) Analog input/output tests - Exercise the analog devices through their full range of operation. This is accomplished in a closed-loop fashion using known calibrated digital-to-analog converters as a reference. The test is compiled so that the operator can specify the accuracy limits to which the equipment will be tested, and it readies the period and amplitudes of test signals via an on-line input device. All converters, multiplexers, and demultiplexers are tested, and all channels not functioning within specified limits are printed out on the teletypewriter.

e. Real-time Clock Test - Automatically checks the real-time clock for proper functioning and accuracy and automatically prints out the results on the teletypewriter.

Device 15E18, Tactical ECM Trainer, has a unique feature called a maintenance panel which is separate from the computer. The maintenance panel has various switches which enable the operator to take the computer off the line (when a problem is suspected in the computer), and step through the program manually, one word at a time. The panel can also be used to fault isolate to the LRU (line replaceable unit) level within the trainer. This concept of BIT is relatively simple and inexpensive to develop and is well-suited to smaller trainers in which elaborate software programs are not justified.

Another approach to BIT is the incorporation of off-the-shelf data logging equipment into the trainer design. Such a system built around a programmer comparator contains the following elements:

a. An operator's console, including control and display devices to present the evaluation of the tests to the operator.

b. Programming equipment that provides coordinated and precise control of the test equipment and the unit under test by using prepunched or magnetic tape.

c. A stimulation control unit that provides signals to be injected into the unit under test.

d. An adapter unit that is the link between the tester and the unit under test.

e. A test point switching unit that selects test points determined by the programmer and routes the signals to the test evaluator.

f. A comparator that accepts the information from the test points as ordered by the programmer and determines if the selected test results are within permitted tolerance.

g. A measurement unit which provides a standard for the comparator. Depending upon the encoded instructions and the results of the comparison, the test system may proceed to the next test, stop and allow the operator to make the next decision, or automatically search to a desired sub-routine for further evaluation of the malfunction.

Keep in mind, that so far, we have only discussed on-line testing. Once a module or assembly has been declared faulty and has been removed for off-line checkout, another type of BIT equipment comes into play. This particular equipment may or may not actually be built-in, but nevertheless, its importance can not be overemphasized. This is the assembly or module tester. Sophistication is definitely in order for the assembly tester. MIL-T-23991 specifies that all assemblies in the training device which are used more than five times must be checked on an automatic or semi-automatic test system, whereas assemblies which are used less than five times may be tested manually. A complete assembly tester will have power supplies, signal generators, oscilloscopes and other measuring equipment built into the tester. The tester should be capable of testing all cards and modules used in the trainer, including those used in the computer. It is desirable to have the tester programmable by means of a punch tape, punch card, or patch board. Special loads and other passive signal conditioning elements should also be included in the tester.

All that was discussed exists in training devices today. Where do we go tomorrow? We are always receptive to new ideas and breakthroughs in the field of testing as you submit proposals on new training devices. First, train your designers to be conscious of the maintenance problem and help them become familiar with the latest techniques in BIT. Then the bids will tend to be reasonable and trainer BIT capabilities will grow. One of the most outstanding sources of up-to-date information in the realm of BIT and automatic testing is PROJECT SETE which is conducted by New York University School of Engineering and Science. The project director's name is David M. Goodman. You can obtain a wealth of information from Mr. Goodman in the form of study reports, lecture papers, and actual instruction classes. You're missing a good source of information if some of your key people aren't on-board with Project SETE.

THE DRAGON ANTITANK MISSILE SYSTEM TRAINING EQUIPMENT AND GUNNER TRAINING

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The requirement for a medium range antitank/assault weapon that would provide the infantryman with an improved capability against tanks and hard targets over that provided by its predecessor, the 90MM recoilless rifle, was stated in a Qualitative Development Requirement Information document released by Ballistic Research Laboratories in October 1962. A United States Army Combat Developments Command Small Development Description, dated October 1968, identified the requirement for a Conduct-of-Fire Trainer to be used with this system. To meet these requirements, McDonnell Douglas Astronautics Company, TI-CO, developed the DRAGON Weapon System and its allied training equipment.

Prior to describing the training equipment, it is necessary to briefly describe the weapon system.

THE DRAGON WEAPON SYSTEM

The DRAGON is a one-man portable and operable, command to line of sight wire guided missile system. It consists of a tracker and a round.

ROUND. The DRAGON round consists of a launcher and a missile, packaged together, and is the expendable portion of the system.

1. The Launcher - The Launcher consists of a smooth bore fiberglass tube, breech, canister assembly, tracker mount, support stand, launcher wiring harness assembly and tracker battery, carrying strap, forward and aft shock absorbers. It is disposed of after the missile has been fired. The Launcher has an overall length of 44.10 inches and weighs approximately 8.9 pounds, without the missile. The high pressure canister and low pressure breech configuration supplies the required muzzle velocity without exceeding the permissable acceleration levels and with a minimum of recoil. The Launcher also serves as a storage and carrying case for the missile prior to launch.

2. The Missile - The Missile is the second item of the round. The missile consists of three major sections. The forward section contains the warhead and fuze system. The center section contains 30 pairs of side thrusters and their firing circuit boards. The aft section contains the electrical components assembly, control system electronics package, flare assembly, bobbin assembly, and three folding fins mounted on the sleeve assembly. The missile is approximately 28.5 inches in length, has a diameter of approximately 5 inches, and weighs approximately 14 pounds at launch.

TRACKER. The Tracker is the reusable component of the DRAGON Weapon System. It consists of an optical sight and infrared sensor, which are boresighted to each other, an electronics package, trigger, and a structure assembly. The tracker measures the displacement of the missile from the line of sight established by the gunner. Missile displacement measurements made by the tracker are converted to guidance commands which are transmitted to the missile by a wire link. The guidance commands produce horizontal and vertical missile control forces generated by small thrusting rockets which are mounted canted in the missile so that longitudinal thrust is also produced, thereby increasing the missile's forward velocity. The tracker determines missile position from the IR flare assembly at the aft end of the missile. A typical test launch is shown in figure 1.

Figure 1. Dragon Weapon System Firing

The simple but sophisticated DRAGON Weapon places the gunner in a new environment as compared to the 90MM recoilless rifle which it replaces. The gunner functions can be divided into four separate events:

1. The prefire function; i.e., the preparation of the weapon and the acquisition of the target.

2. The launch function; i.e., the trigger squeeze and control of launch reaction.

3. The post launch function; i.e., maintain a proper sight picture while tracking smoothly.

4. Post impact function; i.e., the removal of the tracker from the "spent" round and the preparation for refire if necessary.

The functions that occur in event one and four do not depart appreciably from the operation of other weapons. However, the functions which are required in events two and three are a radical departure from earlier systems. The student gunner must become accustomed to the time delay between trigger pull and launcher firing and must also learn to control his reactions to the large percentage of system weight loss during launch. After launch, function three, the gunner must suppress the natural reaction to put the weapon down, and continue to track the target with a smooth and steady motion regardless of the events which are taking place around him.

THE DRAGON TRAINING EQUIPMENT

The "Training Package," i.e., the training equipment and the training plan, is an important element of a weapon system development. The value of the training package is dependent upon proper assessment of two areas:

1. What is necessary to be learned by the trainee ?

2. What technological abilities; i.e. skill and knowledge does the prospective trainee possess which can be used during his training?

The training package should create a realistic environment for maximum effective learning to take place. Galileo said, "You cannot teach a man anything...you can only help him find it within himself." We are no longer satisfied just to teach a man something. If we are to have effective learning, we must use new and imaginative training equipment and techniques to help him find the skills within himself.

The DRAGON Training Equipment does create a realistic handling and launch environment. It also employs immediate feedback techniques in terms of gunner performance. The DRAGON Training Equipment provides the tools for developing and maintaining the gunner's proficiency, reduces the need for expending live missiles for training purposes, and evaluates the gunner's performance instantaneously.

The training equipment consists of the Launch Effects Trainer (LET), Infrared Transmitter, and the Monitoring Set as shown in figure 2. During training exercises the LET uses a tactical tracker for gunner sighting, and provides a launch recoil comparable to that of the weapon.

Figure 2. Dragon Training Equipment with Infrared Transmitter Mounted on Jeep

Launch Effects Trainer (LET). The Launch Effects Trainer simulates the Weapon Round in appearance, prefire weight and center of gravity and therefore can be used for handling and set-up exercises. The LET employs the energy of a 7.62 blank cartridge to produce an audible blast as well as the recoil and the weight shift effects of the tactical round. The internal arrangement of the LET is shown in figure 3.

For a training exercise, the student gunner executes the same prefire functions in using the LET as are required by the tactical weapon. These functions consist of the following:

1. Mount the tracker on the round

2. Lower the support stand

3. Assume firing position

4. Acquire target with tracker telescope.

A training assistant sets and locks the weight shift assembly into firing position and then opens the breech and inserts the cartridge. This requires removing the access portion of the aft shock absorber and opening the breech. Opening and closing of the breech cocks the firing mechanism and automatically sets the safety cam to the safe position. The complete sequence of events for LET firing is shown in figure 4.

LAUNCH EFFECTS TRAINER SUB-ASSEMBLY

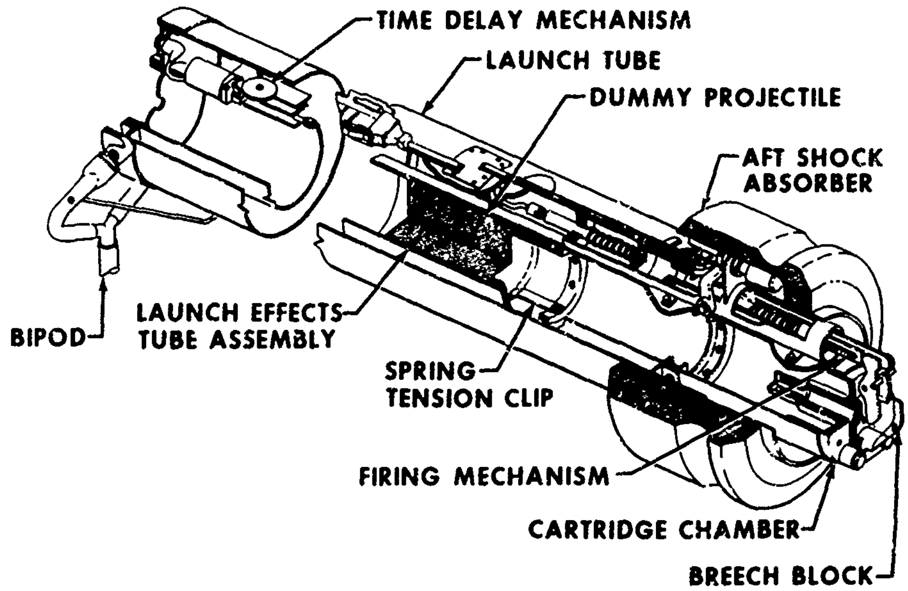

Figure 3. Launch Effects Trainer Subassembly

LET OPERATION

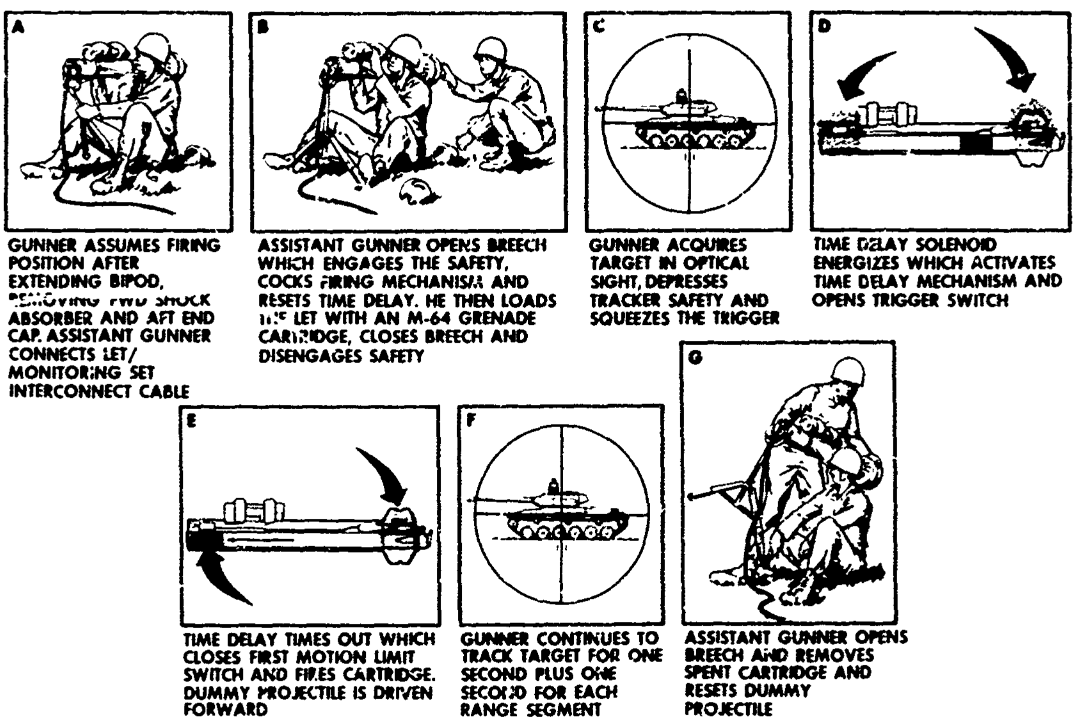

Figure 4. LET Operation

Infrared Transmitter. The Infrared Transmitter provides the necessary energy for establishing tracker sensor contact with the target. In so doing the Infrared Transmitter effectively simulates the missile flare. All visible wavelength infrared energy is filtered out to insure that the gunner tracks a target of realistic contrast and not the transmitter. Displacement of the transmitter beacon from the target aim point is compensated for at the Monitoring Set. Consequently, angular displacement between the sensor optics line of sight and the transmitter is detected as a gunner aiming error during a tracking exercise. The IR Transmitter can be vehicle mounted or stationary mounted to provide simulated stationary or moving targets.

Monitoring Set. The Monitoring Set consists of a control and indicator panel, control logic, error detector, function generator, battery and battery charger. A tracking indicator is provided to enable the instructor to instantaneously monitor the gunner's performance. A target range switch enables the instructor to compensate for target range and to review the various increments of the tracking period. An off target indicator, divided into four quadrants, indicates the direction of the error. Hit and miss indicators provide a readout at the end of a tracking period. Other controls are provided for recorder, target size, horizontal and vertical bias adjustments, an IR transmitter and trigger indicators. The bias adjustments are used during trainer set-up boresighting procedures to null error signals due to displacement of the aiming point from the Infrared Transmitter beacon.

Gunner tracking data is obtained from the tactical tracker, mounted on the LET, which measures the angular deviation from line-of-sight to the IR transmitter located on the target. The Monitoring Set processes, evaluates and displays the angular data received from the tracker. The instantaneous angular deviations from the correct aim point are evaluated by comparing these error signals to a programmed acceptance curve. When a gunner stays totally within the acceptance curve, in both horizontal and vertical throughout the tracking exercise, he is considered as having hit the target. If he exceeds the curve at any time, he is considered as having missed the target, with the approximate time and direction of the error being recorded and displayed at the end of the exercise. A score (0 to 100%), which is based on the gunner's average tracking error, is also displayed. These displays help the instructor evaluate the gunner's performance immediately and can be used to instruct the gunner on methods of improving his skill before his next firing.

THE DRAGON GUNNER TRAINING PROGRAM

The DRAGON Training Equipment has been integrated into and is being utilized in a gunner training program. The training program is divided into four phases of instruction which are presented in an order which reinforces the training objective.

The four phases consist of the following:

1. Technological Knowledge Development
2. Primary Skill Development
3. Instructional Firing

4. Marksmanship Skill Development.

During the development of the student gunners technological knowledge he learns the general characteristics of the DRAGON in terms of the requirement for the weapon, where it will be found in the Army TO&E as well as the DRAGON's physical characteristics and performance. The introduction to the training equipment, including assembly, disassembly, and malfunction immediate action, is also covered.

The Primary Skill Development phase begins with the identification of the motor skills which the gunner must employ to properly utilize the DRAGON System effectively. Each step required to prepare for an engagement of a target (target acquisition, range assessment, target tracking before and after fire) is demonstrated and then practiced to perfection by the student. The pros and cons of each of the firing positions are also discussed and demonstrated during this phase. The look alike, function alike features of the Launch Effects Trainer allows the student to practice in a realistic environment without the potential hazards of the tactical round.

During the Instructional Firing phase the student gunner begins to put into practice those safety procedures, which must be observed, with the tactical weapon when operating in the real launch environment. While serving as an assistant instructor the student becomes thoroughly familiar with the operation of the LET. That is, he learns those functions which are required to operate the LET, but are not gunner functions, when firing a tactical round. He also learns to operate the Monitoring Set.

During Marksmanship Skill Development which is the final phase of the training program, the gunner is scored on each of the simulated firings with the LET. The Monitoring Set pr des the instructor with instantaneous indications of the gunner's performance in terms of the gunner's ability to recover from the launch environment, steady state tracking ability, and the instructor and student the ability to take the necessary corrective action on each shot. As a conclusion to this training program the last twenty firings are for a qualification score.

CONCLUSION

The simplicity of operation of the DRAGON Weapon System, excellent positive transfer characteristics of the DRAGON Training Equipment combined with a well developed training program have made it possible to demonstrate that more than 99 percent of the selected gunner candidates can qualify as Army "DRAGON" Gunners.

INNOVATIONS IN LAND COMBAT TRAINING

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INTRODUCTION

Since the last Industry Conference, we, at the Army Training Device Agency, have been getting a good deal of exposure throughout the Army. In the last 12 months we have had most of the CONARC Training Center Commanders visit us; in addition, General Westmoreland attended a demonstration of our Synthetic Flight Training System prior to its installation at Fort Rucker. On 1 July of last year, we changed our name to be more descriptive of what we do. (See figure 1.)

Figure 1. Name Change

Getting General Haines and General Hunt here today is indicative of the command interest in training devices and simulators. Fortunately, I had some prior knowledge of General Haines' presentation so I intend that my paper be considered an extension of General Haines' remarks with emphasis on the need for training devices and simulation techniques for land combat training.

I have divided my paper into several parts. Initially, I would like to tell you a little about the Board for Dynamic Training; secondly, what I saw in Europe at several foreign training centers last September; thirdly, a discussion of cost-avoidance on a trainer in use in Europe; and lastly, what the future looks like for land combat training device developments.

ARMY TRAINING POLICY

In September of last year, General Westmoreland released a message on the subject of Army training policy. This message established a Board for Dynamic

Training to forge a new link between the managers of combat arms training, including both the Reserve and National Guard, and the Army's extensive training establishment. The short and long range goals of this link are to provide the unit training managers the expertise found within the training establishment to accomplish their training mission within the assets locally available. The Board is headed by General Paul F. Gorman, Deputy Commandant of the U.S. Army Infantry School, and responsive to the direction of the Commanding General, CONARC. The primary thrust of the Board for Dynamic Training will be to produce a catalog of idea-stimulating material on how to organize and conduct effective, stimulating, adventurous training and how to conduct training on tactics and weapons despite limitations on training areas or conditions of under-strength.

I think I can say without hesitation that if you have any innovative ideas about any area of training, whether it is in the area of devices, methods, or literature, you will find in General Gorman and his people, a receptive audience.

FOREIGN TRAINING

In September of last year I was fortunate to be a member of a Department of the Army team, which visited several German, French, and British Army training facilities to see what innovations they had that our Army might use. We saw some simple and very interesting training methods. I would like to show you some pictures taken during my travels. Figures 2 and 3 show subcaliber firing at the German Artillery School with miniature targets located approximately 100 yards away at the outer perimeter of a small field.

Figure 2.

Figure 3.

Figures 2 and 3. Subcaliber Firing at the German Artillery School

This next series, figures 4, 5, 6, 7, 8, 9, and 10, taken in the German Tank School, show a miniature range and some of the various targets in Tanks are driven up to this range and the crew goes through gunnery exercise with subcaliber ammunition, as they would if they were firing full-size live ammunition. We know of no such range as this in use in the U.S. for tank gunnery.

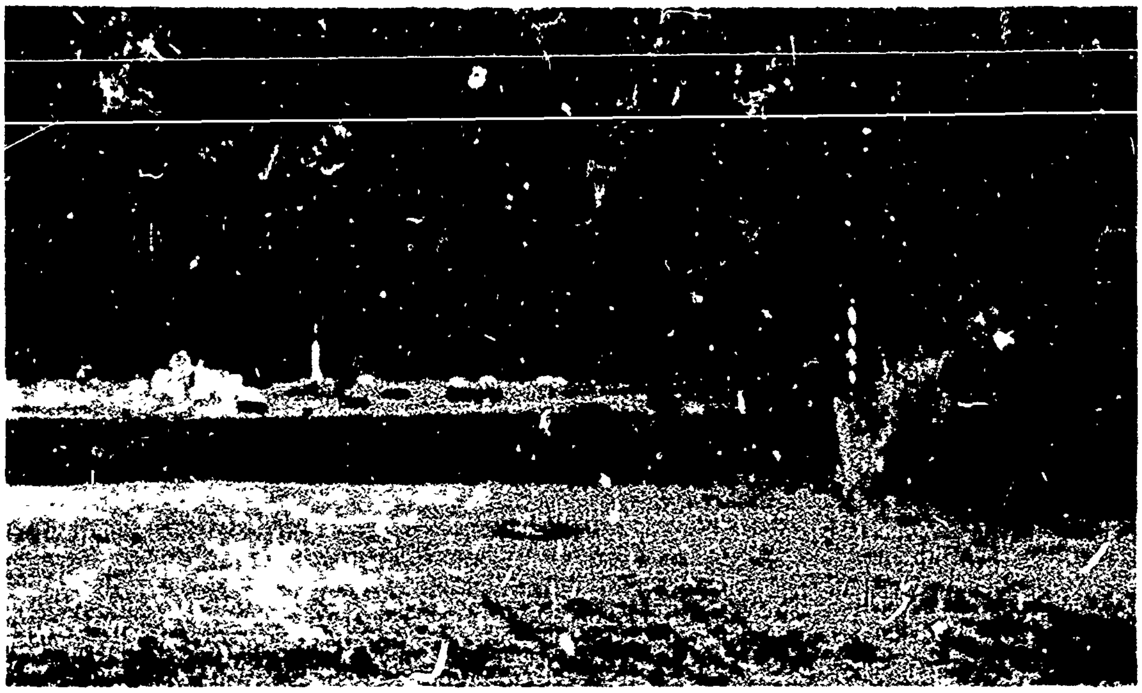

Figure 4.

Figure 5.

Figure 6.

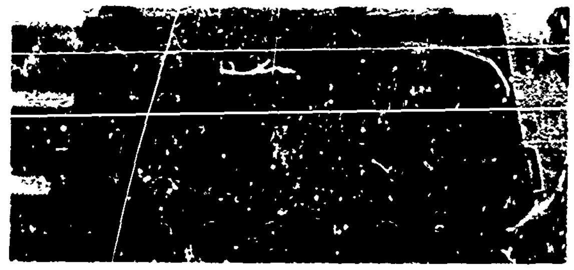

Figure 7.

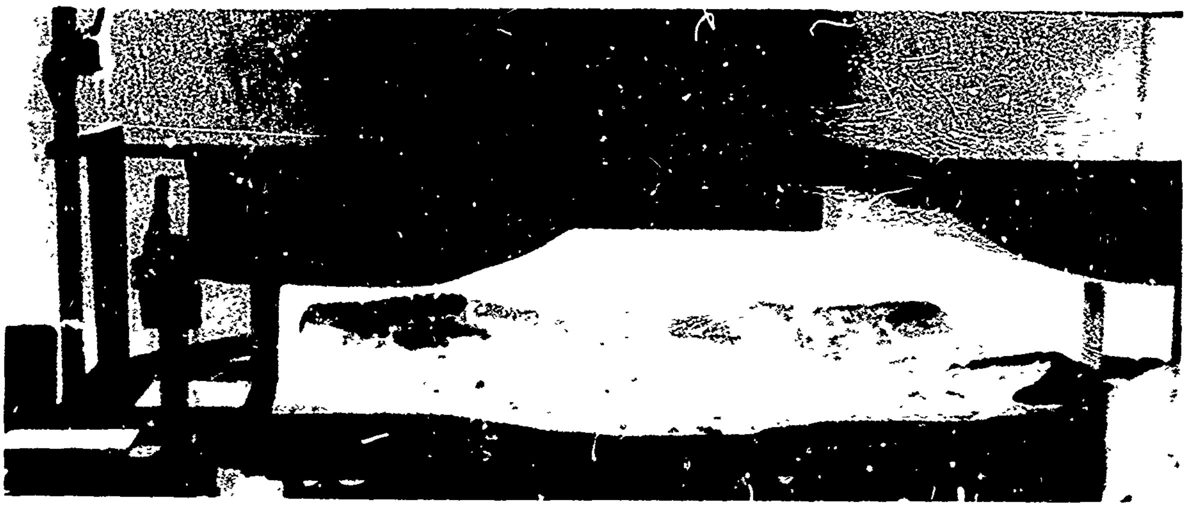

Figure 8.

Figure 9.

Figure 10.

Figures 4 to 10. Miniature Range and Various Targets in Use at the German Tank School

The following figures 11, 12, 13, and 14 show a British method of training tank crews which is very similar to the methods we use in Germany. While we did not see the French Armor School, we were told they trained in a similar fashion.

Figure 11. NOT REPRODUCIBLE

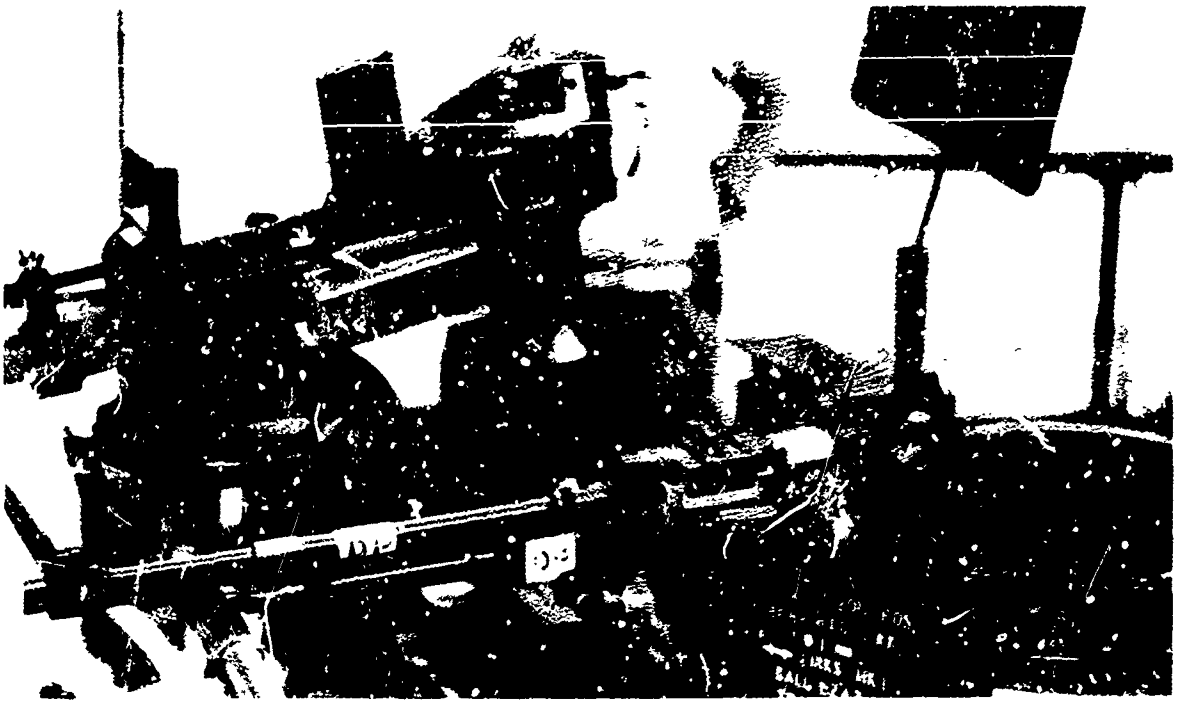

Figure 12.

Figure 13.

Figure 14.

Figures 11 to 14. British Training Tank Crews

A French missile trainer is illustrated in figures 15 and 16. The gunner controls a spot of light which simulates wire-guided missiles. It appeared to be somewhat similar to what we had done in our Shillelagh trainer. The most sophisticated trainers were the driver trainers in use in both Germany, Belgium, and England, utilizing a terrain board 10' x 30' with a television pickup. The device is used to train tracked vehicle drivers. It simulates various types of terrain and is capable of training in emergency procedures. The driver's compartment contains a motion platform with either two or four degrees of freedom.

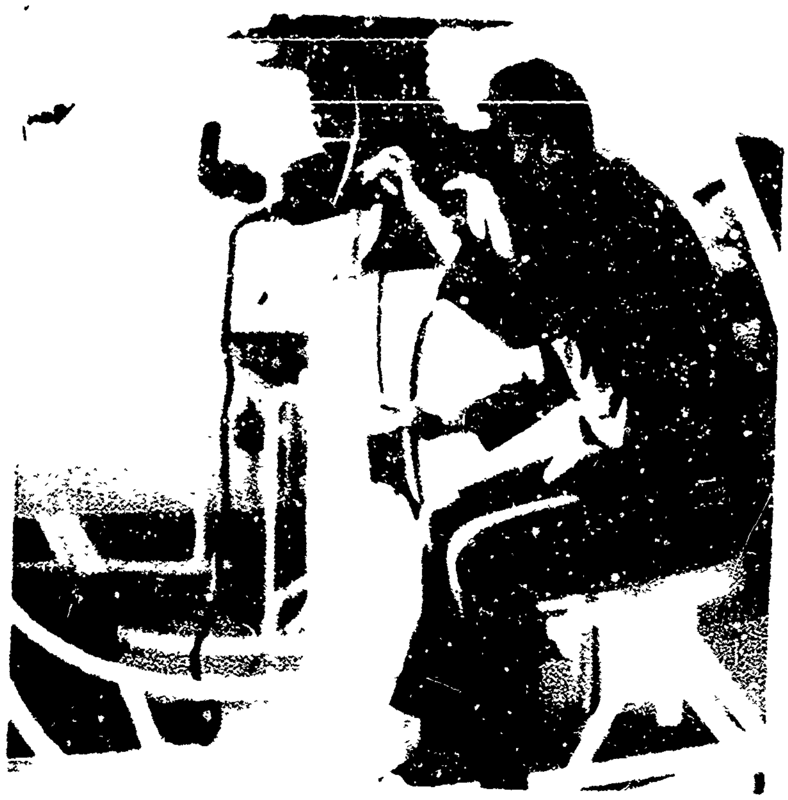

Figure 15. French Missile Trainer (Side View)

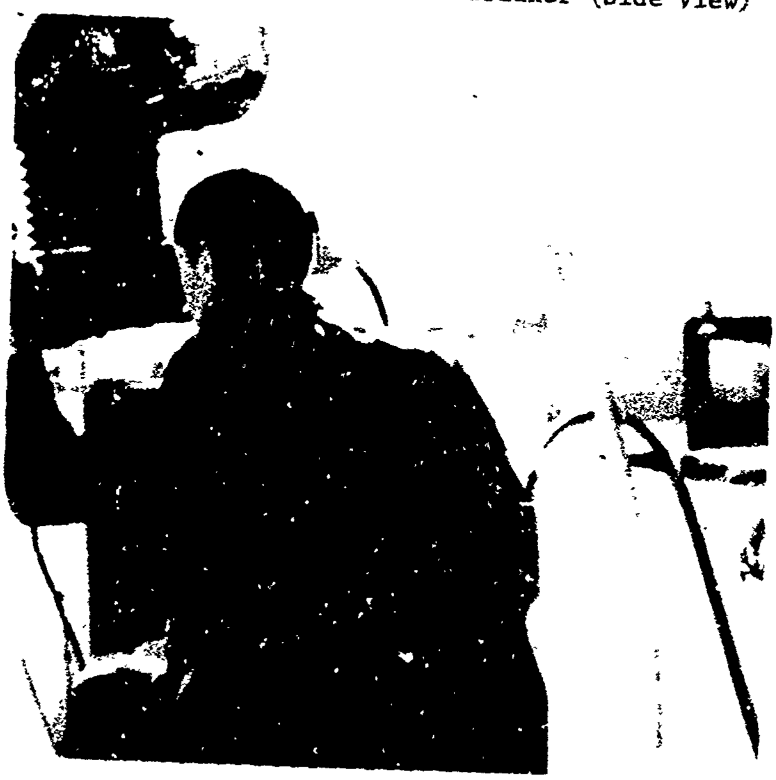

Figure 16. French Missile Trainer (Rear View)

COST-AVOIDANCE

Concerning this trainer, I would like to discuss an aspect of cost-avoidance, (figures 17a, b, and c), or cost savings, (figures 18a and b), which illustrates the economics of an effective trainer. The figures apply to the procurement of a driver trainer for the Leopard tanks which are used by both the German and Belgian armies. (See also figures 19 and 20.)

COST-AVOIDANCE -- TANK DRIVER TRAINER

COST STUDIES UNDERTAKEN INDEPENDENTLY BY THE FRENCH ARMY FOR THE AMX-30 TANK AND BY THE BELGIAN ARMY FOR THE LEOPARD TANK REVEAL THAT THE USE OF SIMULATORS FOR TRAINING TANK DRIVERS SAVES APPROXIMATELY 60% OF NORMAL TRAINING COSTS.

Figure 17a.

EXAMPLE

NUMBER OF TRAINEES: 600 DRIVERS PER YEAR.
TRAINING TIME PER DRIVER: 11 HOURS ON THE TANK - OR
7 HOURS ON THE SIMULATOR
+4 HOURS ON THE TANK

AVAILABILITY OF TANKS FOR TRAINING: 250 HOURS PER YEAR.

HOURLY COST OF TRAINING ON TANKS: $325.00 PER HOUR (INCLUDING DEPRECIATION COSTS OF TANK, MAINTENANCE, SPARE PARTS, FUEL, ETC.).

AVAILABILITY OF A TANK SIMULATOR: AT LEAST 160 HOURS PER MONTH, OR 1920 HOURS PER YEAR.

ACTUAL USE, DEPENDING ON TRAINING PROGRAM: 1500 HOURS PER YEAR.

HOURLY COST PER SIMULATOR: $40.00 PER HOUR (INCLUDING DEPCRECIATION COSTS OF SIMULATOR, MAINTENANCE, SPARE PARTS, ELECTRICAL POWER CONSUMPTION, ETC.).

Figure 17b.

COST OF TRAINING DRIVERS

600 DRIVERS, EACH SPENDING 11 HOURS ON THE TANK, REQUIRE A TOTAL OF 6600 HOURS PER YEAR.

THIS REQUIRES $\frac{6600}{250}$ = 27 TANKS - AT A COST OF $325.00 X 2400 = $780,000.

600 DRIVERS, EACH SPENDING 7 HOURS ON THE SIMULATOR, REQUIRE A TOTAL OF 4200 HOURS PER YEAR.

THIS REQUIRES $\frac{4200}{1500}$ = 3 SIMULATORS - AT A COST OF $40 X 4200 = $168,000.

TRAINING THEREFORE REQUIRES A TOTAL OF 10 TANKS + 3 SIMULATORS AT A COST OF: $780,000 + $168,000 = $948,000.

Figure 17c.

SAVINGS

THIS COST ANALYSIS SHOWS ANNUAL SAVINGS OF: \$2,745,000 - \$948,000 = \$1,197,000, OR APPROXIMATELY $\frac{\$1,197,000}{600}$ = \$1,995 PER DRIVER, OR A PERCENTAGE SAVING OF 56%.

THE EQUIPMENT REQUIRED AMOUNTS TO: 10 TANKS + 3 SIMULATORS INSTEAD OF 27 TANKS.

Figure 18a.

ADVANTAGES

- TRAINING CAN BE ACCOMPLISHED INDEPENDENTLY OF LOCAL WEATHER AND TOPOGRAPHICAL CONDITIONS.
- TRAINEES CAN FAMILIARIZE THEMSELVES WITH ALL-WEATHER OPERATIONS, WITH COLD-WEATHER STARTING (-15°C), DRIVING ON ICY OR SNOW-COVERED SURFACES, ROUGH GROUND AND MOUNTAIN ROADS, FAST DRIVING ON DRY OR WET ROADS, ETC.
- THE INSTRUCTOR CAN INTRODUCE MALFUNCTIONS WITHOUT DANGER AND REPEAT AN EXERCISE AS OFTEN AS NECESSARY.
- THE INSTRUCTOR CAN MONITOR TRAINEE'S PERFORMANCE UNDER SIMULATED EMERGENCY CONDITIONS SUCH AS POWER FAILURE, BRAKE FAILURE, LOSS OF TRACK, ETC.
- A SIMULATOR CAN BE USED AT LEAST 160 HOURS PER MONTH, WITH AN AVAILABILITY FACTOR ON THE ORDER OF 99%. THE TANK IS AVAILABLE FOR APPROXIMATELY 20 HOURS PER MONTH.
- TRAINING IS NOT SUBJECT TO WEATHER CONDITIONS OR TANK MAINTENANCE SCHEDULES, ALLOWING FOR UNINTERRUPTED TRAINING PROGRAMS.
- SIMULATOR UTILIZATION CAN BE INTENSIFIED DURING PERIODS OF EMERGENCY WHEN A LARGE STUDENT LOAD IS REQUIRED.

REDUCED TANK MAINTENANCE

BY STARTING TRAINEES ON THE SIMULATOR BEFORE ALLOWING THEM INTO REAL TANKS AVOIDS ELEMENTARY FAULTS WHICH CAN CAUSE VEHICLE DAMAGE (GEAR-BOXES, TRACKS, ETC.), WITH A RESULTING DECREASE IN MAINTENANCE.

Figure 18b.

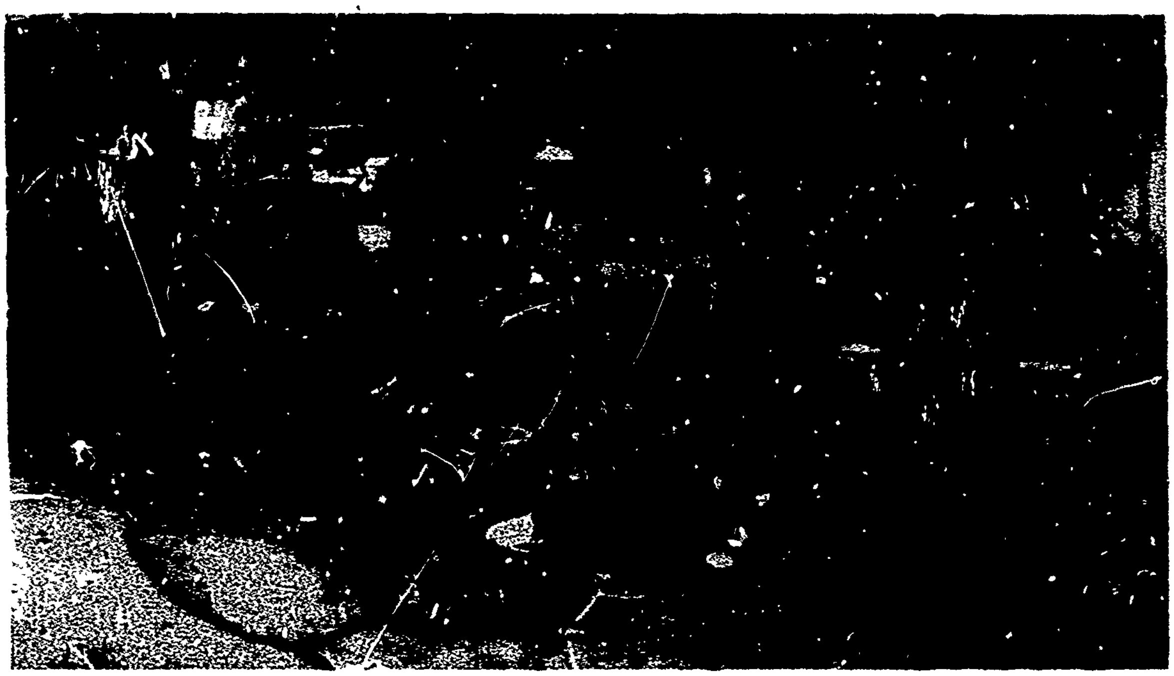

Figure 19. Leopard Tanks Simulated Terrain

Figure 20. Driver Trainer-Leopard Tanks

These figures show how the Belgians reduced the number of tanks to be procured for the training of drivers from 27 to 10 by buying three simulators. I feel sure a similar case can be made for most major weapons; however, we must get into the picture at the earliest possible time. Whether or not trainers or simulators are bought is not important—what is important is that the alternatives are considered.

What I have shown you are just a few of the items we saw in Europe; however, of particular significance was how the training was accomplished. For example: In the British Armor Training Center at Bovington, the schools train instructors selected from units who, after completing their schooling, are reassigned to their units as instructors.

Secondly, it appears that the Europeans are satisfied with a lot less sophistication in their training than we are, because historically their land areas are limited and they have never had the quantities of ammunition nor the training areas that we have had in this country.

Lastly, both the French and the British mount trainers on both land combat vehicles, and helicopters, to simulate weapon firing. This is done even though it may require a reduction in the payload of the vehicle or aircraft. Both the British and French indicated that it was important for fighting vehicles to carry trainers to maintain gunner proficiency.

As I mentioned earlier, we have received a considerable amount of high-level interest in our business. We have conducted an intensified selling program, and the next two figures 21 and 22 show the result of that effort. Two years ago this list contained four or five items—today it is an indication of the added emphasis on training and training devices.

TRAINING DEVICE REQUIREMENTS

LASER TANK GUNNERY TRAINER, XM55 (3A110)
ARMED AIRCRAFT QUALIFICATION RANGE SYSTEM
SYNTHETIC FLIGHT TRAINING SYSTEM (SFTS)
AEROSCOUT AERO VISUAL TARGET ACQUISITION TRAINER
WEAPON STATION TRAINER, MICV-70
COMBINED ARMS TACTICAL TRAINING SIMULATOR
HIT-KILL INDICATOR FOR MBT
FLASH BANG SIMULATOR FOR MBT
XM803 WEAPONS SYSTEM TRAINER
XM803 DRIVER FAMILIARIZATION TRAINER
XM803 DRIVER POSITION TRAINER
XM803 GUNNER FAMILIARIZATION TRAINER
XM803 GUNNER POSITION TRAINER

Figure 21. List of Training Devices

TRAINING DEVICE REQUIREMENTS

XM803 TANK COMMANDER'S FAMILIARIZATION TRAINER
FIELD ARTILLERY FORWARD OBSERVER TRAINER
LARGE SCALE INDIRECT FIRE ADJUSTMENT SIMULATOR
AERIAL TARGET ENGAGEMENT RIFLE (ATER)
LASER RIFLE FIRE SIMULATOR
GROUND OBSERVER RECOGNITION (GOAR) KIT
SAM-D MISSILE TRAINING ROUND/HANDLING TRAINER
SAM-D ORGANIZATIONAL MAINTENANCE TRAINER
SAM-D SYNTHETIC TARGET SYSTEM
AN/PDR-60 RADIACMETER
SATELLITE COMMUNICATIONS EARTH TERMINAL REPAIR TRAINING DEVICE
SAM-D OPERATOR/TACTICS TRAINER

Figure 22. List of Training Devices

LAND COMBAT TRAINING

To begin any discussion of training device requirements for land combat training, the item that immediately comes to the forefront is the recently approved requirement for the Combined Arms Tactical Trainer.

This was alluded to very briefly by General Haines. This device will use a digital computer and a visual display to create simulated combat situations for the Battalion Commander trainee. Training programs will be designed to permit changes in friendly and enemy weapon systems, techniques and organizational structure with the objective of simulating an enemy on various terrains. The intent will be to generate problems and present situations from various perspectives from the Platoon Leader to the Brigade Commander. This device will be the most sophisticated and complex trainer ever undertaken for use by the land combat forces. If it is successful, similar items are envisioned for each of the combat arms schools. This program is a phased development schedule over a three to four year period.

We like to draw an analogy between CATTS (Combined Arms Tactical Training Simulator) for the Army and some of the Navy's sophisticated Fleet Tactics Trainers.

There is going to be a lot of high-level interest in this development and who knows, we may end up with a device which will enable us to be prepared for the next conflict, rather than the last one, which so often has been the case.

We, of the Army Training Device Agency, are in the process of writing memoranda of agreements with several of the Project Managers at the various AMC Commodity Commands. This is in addition to completed agreements with the MBT-70 Project Manager, and ARSV. We have had preliminary discussions with the SAM-D Project Manager, and we anticipate that we will be involved with training devices for SAM-D.

In FY 1973, and hopefully on a continuing basis, we will get funds for new initiatives which are to begin in FY 1972. For many years it appeared that our planning was in reverse. In FY 1972 and FY 1973 we are once more looking ahead.

SESSION IV

Wednesday, 16 February 1972

Chairman: Mr. Emerson J. Dobbs
Head, Sea Requirements and Plans Department
Naval Training Device Center

UNDERSEA WARFARE TRAINING DEVICE REQUIREMENTS FOR THE NEXT QUARTER CENTURY

MR. ALAN J. PESCH
Chief, Man/Machine Systems
Electric Boat division of General Dynamics

Reasonably accurate projections of the result of any multivariate, dynamic process are generally difficult to perform and are rarely made without recourse to large remnant terms. So it is with regard to forecasting training device requirements for the next twenty-five years. What is possible, and perhaps more meaningful, is the projection of current trends in naval missions, hardware, technology, training techniques, and personnel, and relating these trends to training device requirements.

NAVAL ROLES/UNDERSEA APPLICATIONS

Currently, the Navy has four major roles, each of which is being implemented in part through undersea applications. This relationship is described in figure 1. The major trend discerned from this figure is the scope of undersea warfare and the inference of impending increases in undersea applications in the areas of covert deterrence, control, and silent presence.

Naval Roles	Undersea Applications	
	Tasks	Elements
Strategic Deterrence	Secure Patrol	SSBN
Overseas Presence	Attrition	SSN
Sea Control	Denial, Protection	SS, SSN
Projection	Demolition	Swimmers

Figure 1. Undersea Warfare

NAVAL APPLICATION TRENDS

The newer ideas for future naval undersea systems, while difficult to project, will more probably follow the form of functionally specialized units as opposed to multifunction, multilevel command type ships The role of the submarine as an application element is currently growing and will increasingly expand. The principal application will require greater unit specialization, which in turn drives the requirement for improved fleet integration and tactically coordinated operations.

The impact of these applications is obvious: a need for additional tactical commanders, highly skilled in specific mission areas such as ASW deployment, countermeasures, and antishipping missions. These will be similar to the requirements present in the current forms of ASW aircraft such as ANEW and

the role of TACOS in those systems. Factors such as reduced manning, emphasis on the ability to select optimal hardware deployment modes in complex multivariate situations, increased individual control and responsibility, reduction in onboard maintenance through use of more modular systems, and the use of logistics managers instead of maintainers best typify these systems. The training device implications for these systems are shown in figure 2.

Future Naval Applications	Training Device Characteristics
o Larger numbers of tactical command billets.	o Increased trainee throughput
o Requirement for proficient career specialists in tactical deployment.	o In-depth, highly realistic simulations designed to develop individual skills and knowledge.
o Shift from requirements for analog maintenance to digital hardware/software maintenance skills.	o Extensive team training for many teams characterized by ease of availability, detailed performance measures, adaptive training, and secure interconnection of several remote team trainers.
o Small, close knit crews who remain a tactical team for long periods.	

Figure 2. Training Device Characteristics of Future Systems

Hardware Characteristics	Training Device Characteristics
o 1950's--Dedicated special purpose analog hardware.	o Original equipment.
o 1960's--Special purpose digital and dedicated analog.	o Original equipment. Digitally driven increase in simulation fidelity.
o 1970's--Within systems are multifunction digital processors, digital/analog displays.	o General purpose computer displays. Some built-in stimulation/training.
o 1980's--Complete general purpose digital hardware across systems. Adaptive logic, emphasis on software change.	o Major digital integration across various team, force, service trainers. Emphasis on tactical deployment, sophisticated environmental multivariate models, principal training in mental skills vs motor skills. Complete shift from hardware duplication to improving training technology.

Figure 3. Hardware and Training Trends

NAVAL HARDWARE TRENDS

A factor critical in projection of training requirements is the nature of hardware used in implementing the undersea applications listed in figure 1.

Naval hardware trends are shown in figure 3, along with their potential impact on training device characteristics. The major point is that dedicated analog equipment will be replaced by general purpose, multifunction digital processors and displays. This will, in turn, decrease the need for rote (knob and dial) skills and increase the need for in-depth, high-level mental abilities. Future operators will have to integrate the mental load of several watch stations, while rote skills will be performed automatically. In short, hardware will replace operators, per se, and the new systems will require highly knowledgeable decision makers.

Because future hardware will be general purpose, it will also be capable of self-stimulation for onboard training. Training device analysts and engineers will be increasingly required to participate in the design of the actual hardware systems because the systems themselves will be required to perform a significant portion of team and individual training at sea.

This trend also portends a requirement for a pronounc shift in emphasis from the development of training device hardware to the development of training device technology such as computer-aided instruction (CAI), computer adaptive training (CAT), and computer-managed instruction (CMI). Each involves improved measures of performance, training control, and training integration across systems, teams, task forces, and services.

TRAINING TRENDS

The trend to shift from at-sea training to shore facilities will increase in the 1970's. Principal reasons include cost of operation, reduced at-sea duty, and the reduced capability of conducting covert exercises.

This trend will require major increases in simulation fidelity with regard to models of environmental characteristics, sensors, cross-coupling, and multivarying tactical relationships. This same trend affords the opportunity for and, in fact, demands that behavioral scientists develop and apply improved training technology in such areas as CAI and CAT.

In the 1980's, some shore training will shift back to at-sea when complex team training capabilities will be resident in most digital military hardware. At that time the principal shore activity will consist of a continuing emphasis on individual training and preliminary team formulation training.

PERSONNEL TRENDS

Naval personnel will increasingly be forced to specialize in areas of expertise. General responsibilities such as management and tactical command of divisions and subdivisions will narrow down to functional areas such as ASW Tactical Command, Propulsion Systems, Strategic Systems, Sonar, etc. Training re-

quirements will shift from on-the-job training to accelerated in-depth training in subsystem specialties ashore.

Subsystem specialists may require a two- to three-fold trainee output characteristic in comparison to the typical NEC descriptor of the 1960's. Similarly, pressures for improved trainee throughput rates to offset the effects of retention problems will demand improvements in basic instructional technology. Most of these improvements will be required in the form of individualized training devices for "A" schools.

SUMMARY OF PROJECTED TRAINING DEVICE DIRECTIONS

In summary, several major shifts should occur in the direction of training device development. Perhaps the two greatest areas of impact will be the expansion of the role played by behavioral scientists in the implementation of training, and in the development of complex computer simulation models and training executive control programs.

Behavioral scientists will be tasked to precisely define the key elements of training, and then develop accurate mission and behaviorally relatable performance measures and criteria for computer automation and control of training. These efforts must be performed to define the structure of complex executive programs.

Development of simulation models will include: environmental and hardware characteristics; accurate models of other operator inputs for individual training; models of functional teams such as sonar, fire control, etc., for total ship training; and multiple ship operative knowledge for multiforce operations.

Figure 4 lists the principal directions that training device design should take. The trend can be summarized this way: The greatest emphasis must be placed on developing advanced, behaviorally derived training technology as opposed to the past twenty-five years of hardware duplication.

- Stress training technology as opposed to hardware development
- Behavioral scientists should guide training implementation, not device design, for greatest potential payoff
- Improved models for simulation:

    Environment
    Integration across systems
    Sensors
    Operator interaction
    Interactive evaluation

- Shift from training rote skilled operators to complex multifunction decision makers
- General purpose hardware training devices
- Built-in training devices

Figure 4. Projected Training Device Directions

THE FARRAND GROUND EFFECTS PROJECTOR*

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Farrand Optical Co., Inc.

INTRODUCTION

The Farrand Ground Effects Projector is an outgrowth of the Mission Effects Projector which we designed and built for the Apollo Mission Simulators. Mission Effects Projectors were used to provide full color visual simulation for the NASA Apollo Simulators from the launch pad out to and including earth orbit, translunar trajectory and lunar orbit through the use of strip film. From lunar orbit to lunar touchdown a LEM Visual Simulator was used which the Farrand Optical Co., Inc. also designed and manufactured for NASA. The Ground Effects Projector, however, is specifically designed to provide real world views for aircraft flight simulation.

The Mission Effects Projector and the new Ground Effects Projector have very much in common in that they both utilize very wide full color strip film in multiple cassettes and their optical systems,as well as their functioning,bear a close resemblance to each other. The basic difference between the two systems lies in the fact that the Mission Effects Projector, in simulating orbital flights utilizes two-dimensional orthographic color strip film and distorts the imagery to provide a spherical earth view whereas the Ground Effects Projector utilizes continuous full color strip film to provide a full color presentation of simulated aircraft flight and rather than the generation of a spherical earth's view we now provide a perspective generation with vanishing points at the horizon.

One might ask why use strip film when one can utilize either cine-motion film or closed circuit television systems and map models. In the first place, film systems will always supply an inherently better view of the real world than any closed circuit television device can possibly achieve from the standpoint of color, resolution,and realism because films are actual photographs of the real world. Secondly, all film systems are far more compact than any model can ever be and aside from the increased realism, strip films in particular do provide wider operating margins. This last remark should be qualified. Visual simulators utilizing cine-motion projection systems are decidedly limited in translational excursions that can be provided to the simulator. It is the strip film system that provides latitudes and flight corridors far in excess of any model capability. Limits of a typical strip film are shown in figure 5. It is reasonable to ask at this point if film systems are so much better than television then why are closed circuit television systems still used? This question must be answered in several steps. First of all let us consider the cine-motion system. Cine-motion systems provide exceptional realism but there are certain compromises that one must accept.

*Patents Pending

For example,

a. The variation in aircraft velocity cannot safely exceed a ratio of 2:1 with respect to the filming velocity.

b. Cine-motion systems cannot come to a complete stop or cannot make a standing start at any place other than the vicinity where starts and stops were actually filmed.

c. Even with 70mm film the full frame cannot be used for the instantaneous view since a residue surrounding that portion of the frame projected for the instantaneous view is necessary in order to allow for lateral and vertical translations as well as the angular degrees of freedom. These two parameters of instantaneous film projection size versus maneuvering freedom are interchangeable so that available resolution with respect to field of view must be traded against the maneuvering envelope.

d. Since the maneuvering volume is inherently limited by the frame size it is obvious that all maneuvers must be contained well within the filmed view of each frame and so fly-arounds and wide approaches cannot be simulated.

Alternatively, the full color strip film system not only provides all of the advantages of better resolution and realism to a greater degree than the cine-motion film system but it also avoids all of the disadvantages mentioned above.

OPERATING PRINCIPLES

Before we explain the overall system and its advantages, as well as some of its minor disadvantages, it is best to illustrate what we mean by a full color strip film image generator and the difficulties that had to be overcome in order to make such a system functional. In figure 1 it is evident that an aircraft flying a course at constant altitude may photograph a very thin lateral slice of the earth below continously with a strip film camera. At the end of such a mission the "frameless" strip film photography would represent a two-dimensional scale model in full color of the terrain that was flown over. Additionally, if the thin slice photographed were well ahead of the aircraft say at 20° to 30° below the horizon, the two-dimensional rectilinear map model would include the aspect of three-dimensional objects. The right half of figure 2 is a portion of a full color film strip just described which is completely devoid of perspective but which includes aspect. The left half of figure 2 shows the same view but with perspective regenerated. This particular view is confined to include an angle from 30 to 50 degrees below the horizon. At this point, we should say that the method described herein for making a strip film is purely descriptive and far too complex and therefore does not represent the manner in which such a film would be actually evolved.

In order to use this rectilinear two-dimensional model as an image source for flight simulation, one must be able to effectively locate the observer's eye at any altitude h above the film strip as shown in figure 3. The observer must be made to view this film strip out to a tremendous distance such that the angle of no detail below the horizon is minimal, say on the order of 20 minutes of arc. This means that a tremendous expanse of strip film must be used and it must be projected or viewed at such an acute angle that the perspective in the strip film is regenerated. Needless to say, use of any film in this manner is optically impossible and perhaps this is one of the reasons that such a system had not been devised up until the present time. We have been able to provide exactly the required view by the use of optical systems employed in the Apollo Visual Simulator together with a new optical device that regenerates perspective from a perspectiveless film strip.

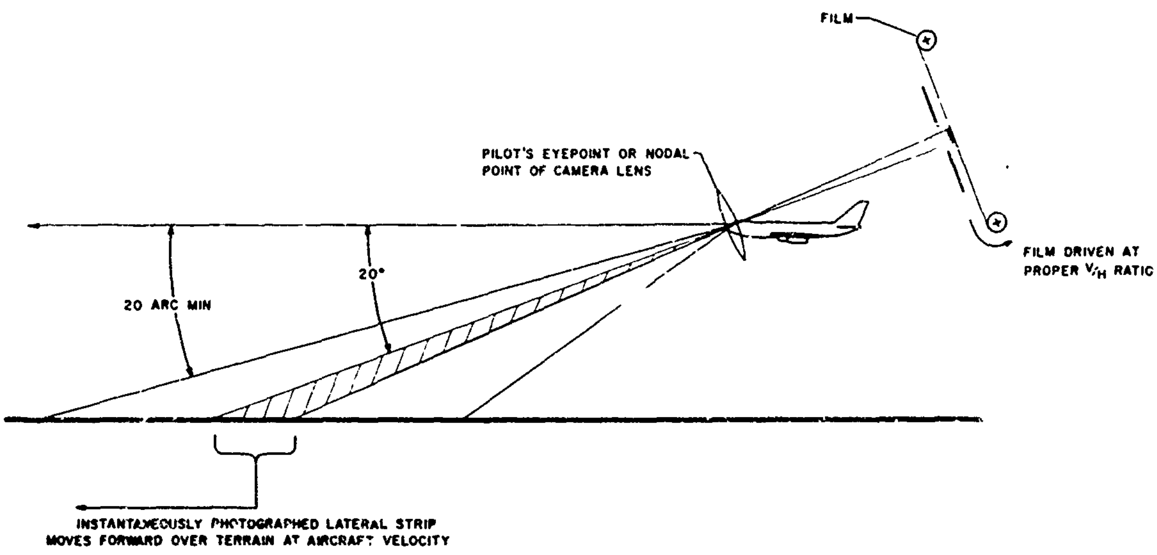

Figure 1. Forward Oblique Film Strip Fotography

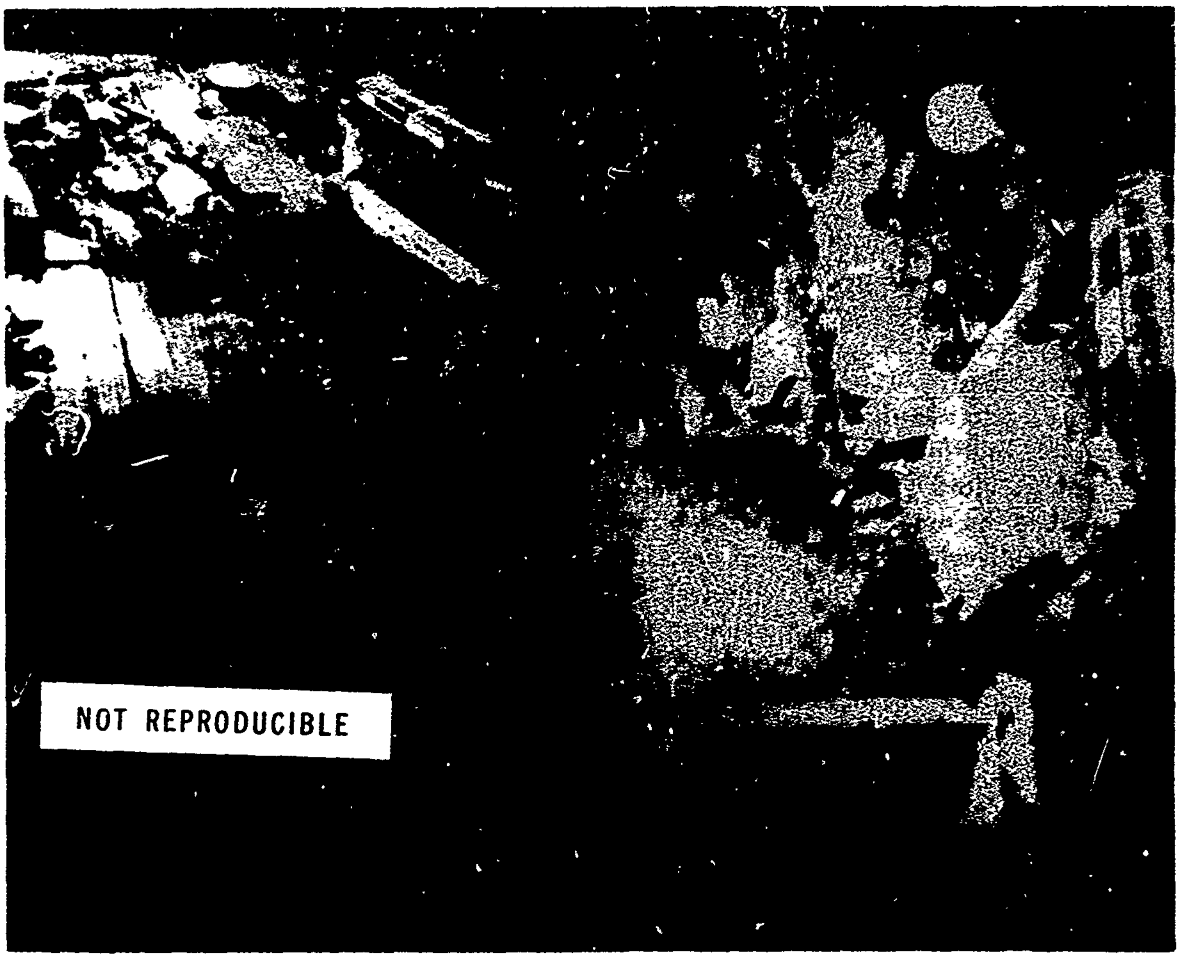

Figure 2. An Orthographic Strip Film View with Aspect is shown to the Right and the same View after Processing by the Perspective Regeneration System is shown to the left

Figure 3 illustrates the strip film principle used in achieving a reconstituted external world view. The system provides an instantaneous terrain view from 1.7h or 1.7 times the eye height forward of the nadir point to 150 h forward of the nadir point, an included vertical angle of approximately 54°. The Farrand Perspective Regeneration System permits the optical system to view the film in an orthogonal manner as shown, thereby avoiding illumination problems as well as shallow angle viewing problems. Note from figure 3 the angle at which the film would have to be viewed from an equivalent eyepoint in order to regenerate the proper perspective if the Perspective Regeneration System were not available — an absolute impossibility!

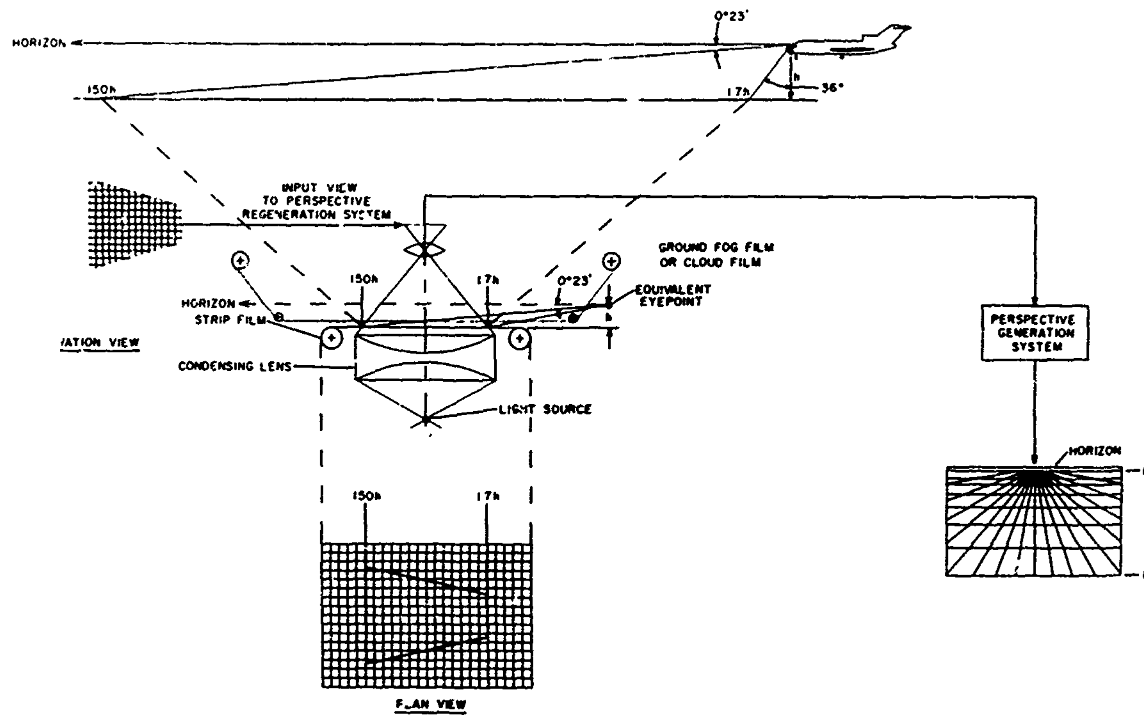

Figure 3. System Diagram

The rectilinear strip film is viewed in an orthogonal manner by a conventional optical system and the image is then processed by the Perspective Regeneration System, reconstituting the perspective out to 150 h or to within 23 arc minutes of the horizon.

Another noteworthy advantage of the strip film system employing a Perspective Regeneration System is the ease with which clouds or ground fog can be realistically simulated. The cloud or fog strip film shown in figure 3 is of linear density but becomes exactly analogous to the real world condition when the Perspective Regeneration System compresses the view vertically and laterally in accordance with elevation angle. This compression parallels true fog or clouds in the real world where the attenuation of visibility is a function of the angle of view through the fog. Because the fog source is of linear density, it is relatively simple to provide accurately repeatable RVR's (Runway Visual Ranges).

Resolution capability of any film system is directly related to the resolution capability of the film and the film patch size used to provide a given field of view. Considering a 136° field of view to provide 95° fields to both pilot and co-pilot with a 54° central overlap angle, the instantaneous patch size required of 5-inch and 9-inch strip films is shown in figure 4. The patches for both strip film sizes are compared to the instantaneous patch size of a 70 mm cine-motion system. When one considers the

relative film areas used for projection, it is obvious that the resolution of either strip film system far exceeds the resolution that can be expected from the 70 mm cine-motion system. Additionally, the resolution increases as the angle of view approaches the horizon because of the compression or minification of the film area.

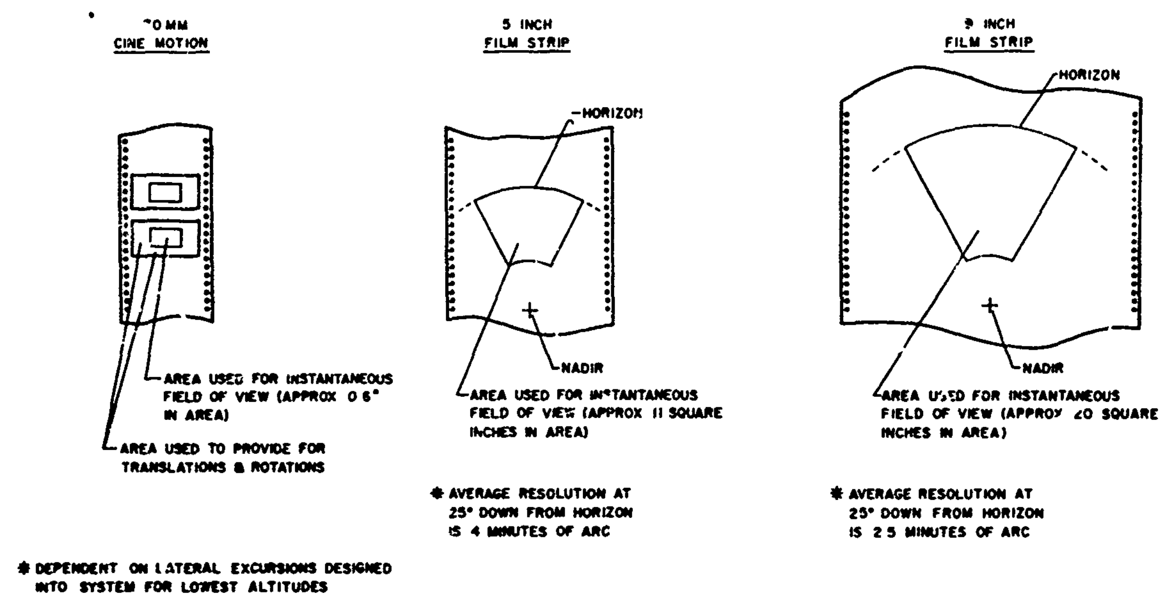

Figure 4. Comparative Sizes of Image Source

PERFORMANCE CAPABILITY OF THE SYSTEM

Details of system operation will not be discussed at this point except for a few principles that will serve to explain the flexibility of the Ground Effects Projector. In order to achieve altitude variation, we employ a 2:1 varifocal lens system as well as a duplicate set of film cassettes. The reason for this duplication is so that when the varifocal lens in either cassette system approaches its limit of operation the adjoining varifocal lens and adjoining cassette system can be gradually brought into operation to replace the original system. In this manner one can leap-frog from one system to the other to almost any simulated altitude desired as long as different scale strip films are available. Switching from one set of cassettes to the other is accomplished by a cross dissolve system exactly in the same manner as was done in the Apollo Simulators. It must be noted at this point that the switching process from one system to the other is absolutely invisible to the observer.

The next point to be discussed concerns the lateral translational capability of a strip film system. Again referring to figure 4 it is seen that the patch sizes used for instantaneous projection do not extend to the edges of the film strip. To simulate lateral translation the film strip is merely translated laterally with respect to the optical system and when visual limits are reached, cloud banks and fog enter the scene so that no abrupt terminations are encountered. Translations are simply simulated because the perspective regeneration system is fixed with respect to the optical axis and, therefore, the horizon remains fixed with respect to the observer and only the film terrain input moves in accordance with the simulated motion of the observer.

Longitudinal translations or forward velocity can actually vary from rearward motion to zero velocity or hovering simulation on up through simulated supersonic and hypersonic velocity since velocity is a direct function of linear film speed -- quite unlike a cine-motion film system where frame rate determines apparent velocity.

The angular degrees of freedom are easily simulated by well-known optical techniques employing scanning mirrors for pitch, cassette rotations for yaw and a derotating prism for roll.

As an example of the maneuvering volume of the Ground Effects System we may refer to figure 5. Each of the rectangles shown in the length profile and in the width profile represent strip films photographed and reproduced in the laboratory to different scales to simulate different mean altitudes. Using a 2:1 varifocal system and using five film strips of different scale we can simulate flight anywhere from touchdown up to a 2287 foot altitude where the aircraft can cross the film strip boundaries anywhere at any time with complete freedom. Note also the extensive width profile which is 42,250 feet at 2287 feet of altitude, 16,800 feet at 925 feet of altitude, and 1350 feet wide at 75 feet of altitude. A final observation on the compactness of such a film model is contained in the note on figure 5 where the total film length for all of the scales shown is only 136 inches.

At this point it would be well to mention that the film strip system so far described is used to generate only terrain views. The sky is separately injected by another projection system. The Ground Effects Projector System not only provides unusual realism for ground fog with exact repeatability of RVR in the manner described previously, but strobe lights are also generated in a unique manner so that frequency can be varied and the strobe effect will never appear to separate from the lamps themselves as very often is the case with cine-motion simulations. A final point to be considered is that the visibility of this system as far as runway lights and runway detail is concerned is too good and must be attenuated to simulate the real world view. The reason for this surprising characteristic is that runway and terrain detail are photographed at a relatively low altitude and all objects are therefore photographed at relatively close distances. This detail appears in absolute clarity on the strip film and when it appears just over the horizon it is generated by large scale film detail which is compressed by the optical system so that such detail appears unrealistically sharp and unrealistically too visible. We might add, however, it is far better to purposely degrade a view than to try to upgrade a scene where the detail is not present.

An additional advantage of the strip film system arises from the fact that the film is practically indestructible. The wear and tear associated with cine-motion systems does not occur with strip film because it is not an intermittent drive, rather it is run through a gate at a simulated aircraft speed which is inversely proportional to the real world scale. Furthermore, the cassettes are so designed that the film itself never comes into sliding contact with any other material; it is in fact supported on layers of cooling air while in the film gate. In addition to this cooling air flow, the strip film is never subjected to excessive heat because of the relatively low flux density of illumination required as a result of the large patch size used for projection. Should a film eventually deteriorate, the cost for replacement is minimal since it involves reproduction of a film length of approximately 12 feet.

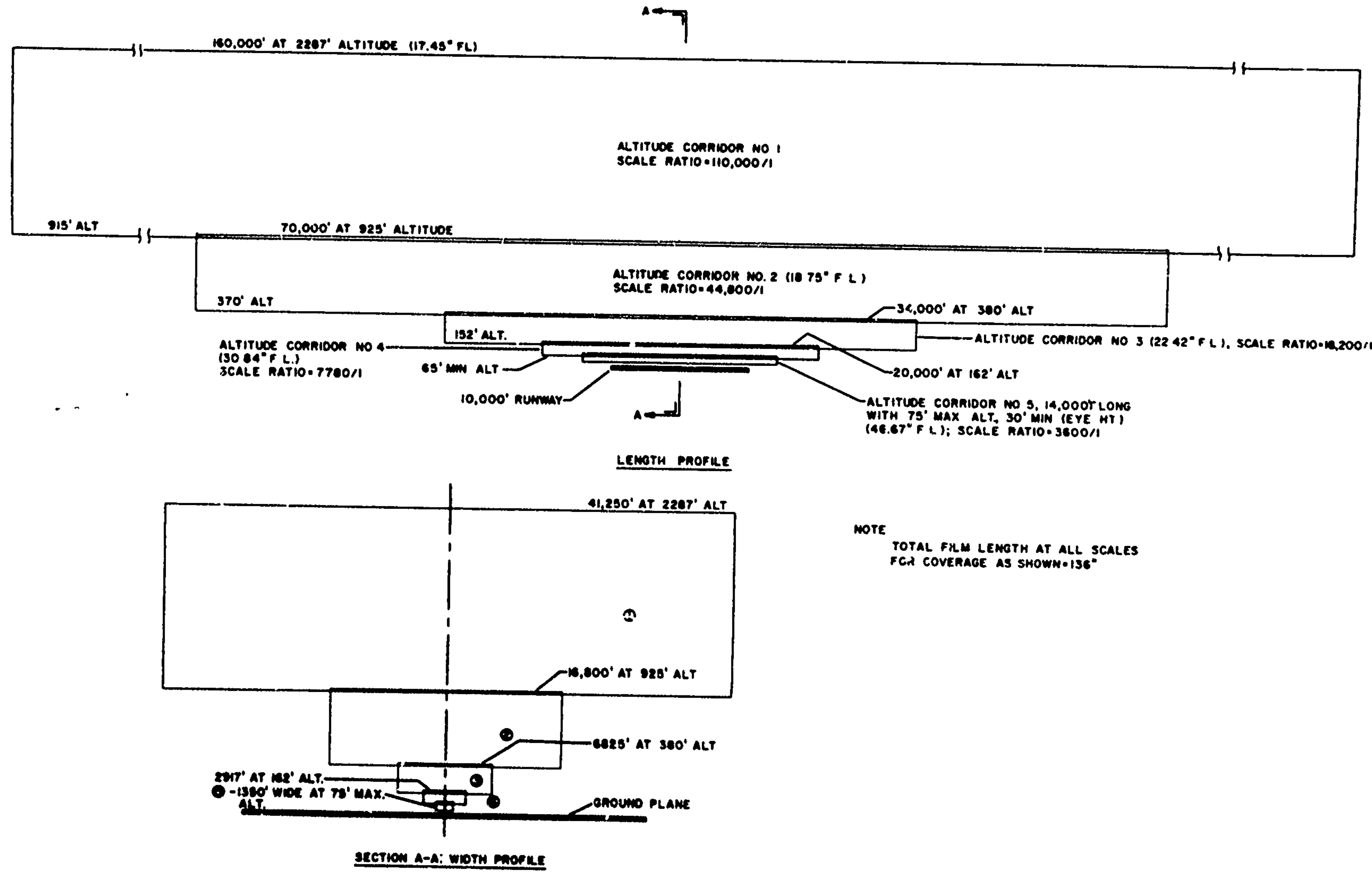

Figure 5. Composite Coverage of Terrain for Five-Inch Strip Film System

LIMITATIONS OF STRIP FILM

Up to this point we have described the advantages of a film strip system without pointing out the limitations. So far as we know there are only three limitations associated with the Farrand Ground Effects Projector System. The primary limitation consists of an apparent lean of tall buildings, a defect which is introduced when regenerating perspective. Originally all detail is rectilinear, however, since buildings can only be represented in two-dimensions, when perspective is generated in the two-dimensional plane, the buildings are made to lean or point towards the vanishing point. For one or two-story buildings at reasonable simulated altitudes in excess of 500 feet the lean is not perceptible when flying at some forward velocity. This defect does not show up when landing on runways since runways are relatively flat with no vertical prominences visible.

The second minor defect concerns the appearance of buildings as we translate laterally in excessive amounts. Since building details are locked into the film we can never fly "around" them and so with large lateral displacements, buildings will always present the same face to the observer. Finally, the last limitation of a strip film system again derives from a two-dimensional film model where vertical prominences cannot be made to rise above the horizon. Fortunately, this limitation does not usually affect a commercial aircraft simulator.

CONCLUSION

In conclusion, it would be well to illustrate not only the size of a film strip system such as we have described but also the fields of view currently available. Figure 6 illustrates the fields of view that can be provided to both pilot and co-pilot using an L-1011 aircraft as an example. Figure 7 shows the film strip image generation or Ground Effects Projector feeding an Infinity Display System where both units are mounted to an L-1011 simulator cab.

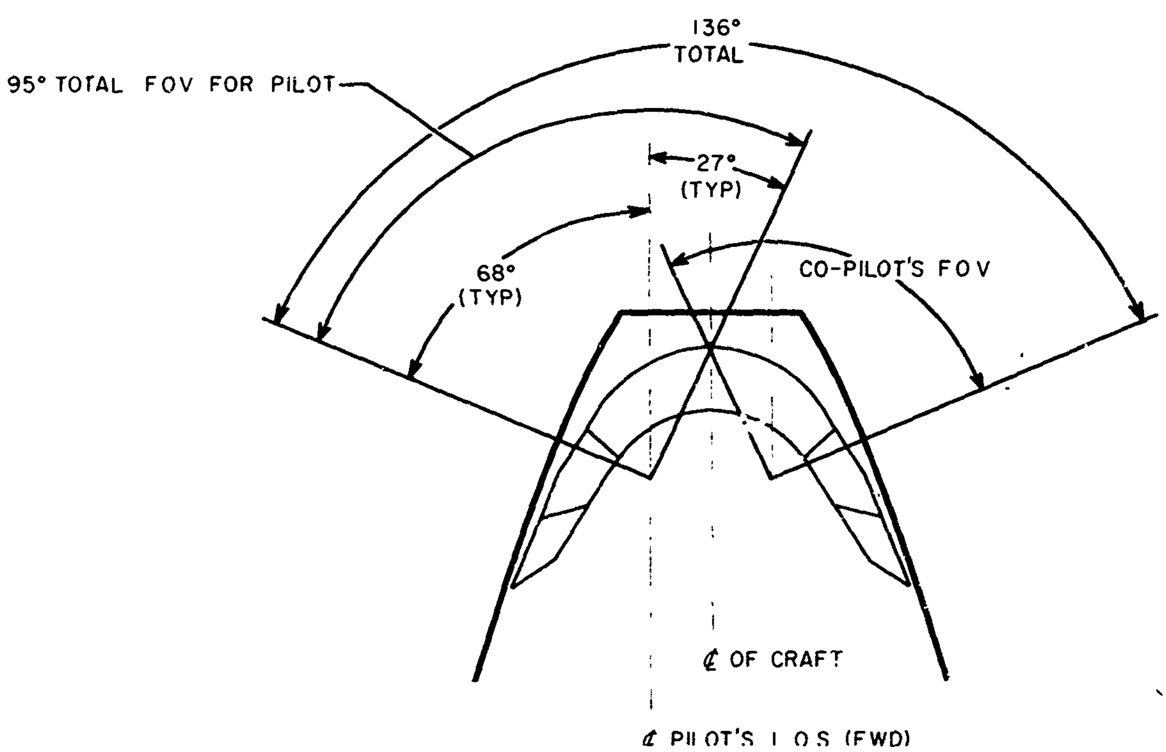

Figure 6 Fields of View, Pilot and Co-Pilot, L1011

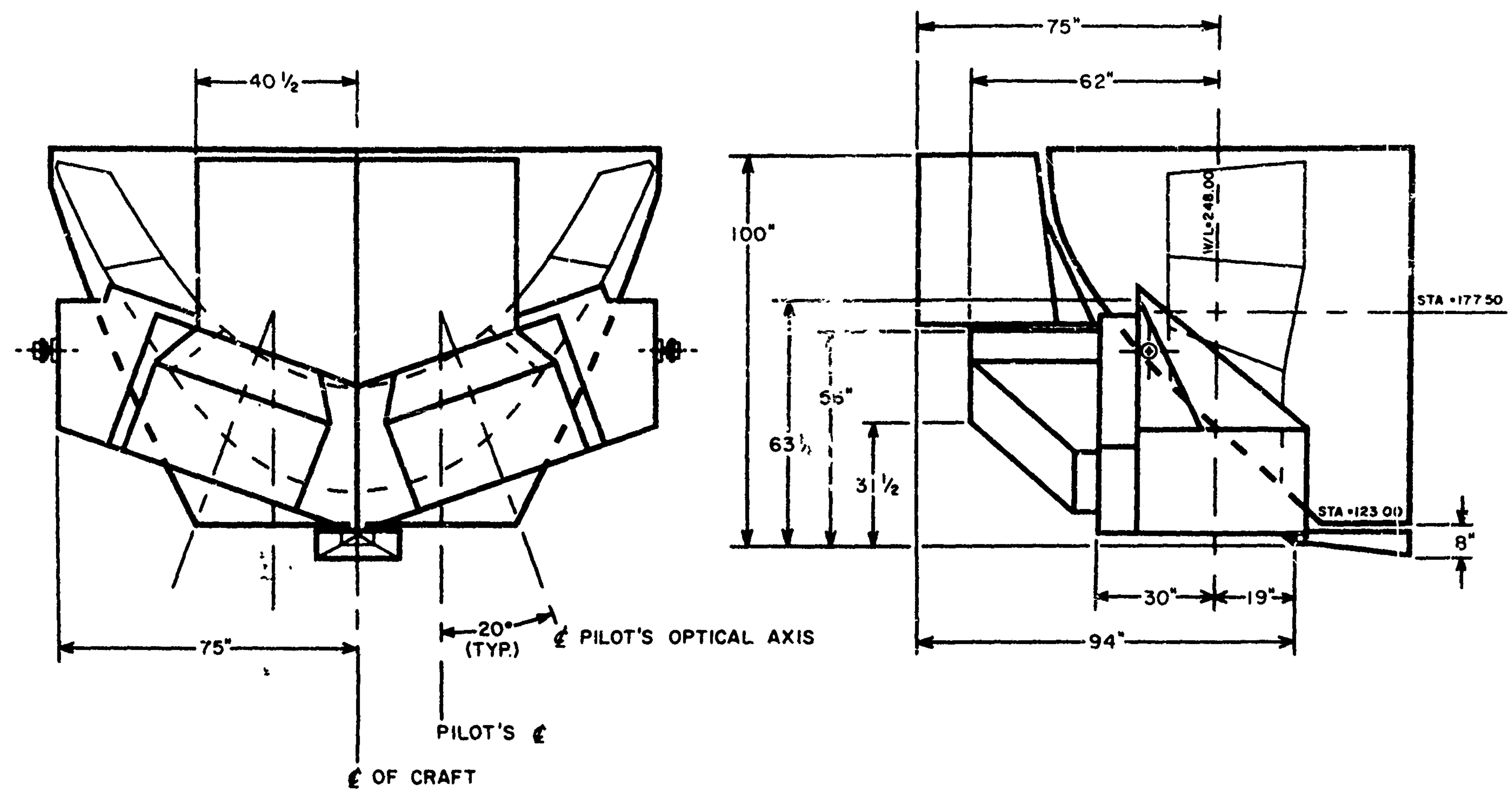

Figure 7. Visual Attachment Schematic, L1011

ADVANCES IN SONAR AUDIO SIMULATION

MR. E.J. WROBEL
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In order that students accept a training device, it is imperative that such a device provide realism, or else it will be merely treated as a sophisticated toy. This is particularly true when the training device patterns a specific operational equipment. Such things as the response to control movement, color of displays and readouts and the "feel" of the trainer contribute to the aesthetic relationship between the trainee and the device. This has manifested itself in the past, where because of the in-depth realism provided, enlisted Naval personnel were willing to sacrifice liberty hours in order to spend more time with the training device. What better index of favorable acceptance could one find?

One area of simulation, that has always posed problems, is that of audio sonar simulation. The human ear is an extremely sensitive sensor and very difficult to fool. The human ear is responsive to transients of very short durations, in the order of tens of milliseconds. Compound this with the wide variations in hearing response — both in amplitude and frequency — that occur between individuals by virtue of heredity, age, and history effects. Thus, if one generates an audio signal, that is not authentic, it will be evaluated as non-realistic by experienced listeners, but in-turn, differently by each individual. To rely on a collection of personnel in evaluation of sonar audio simulation realism can be an extremely frustrating experience.

Therefore, one of the fundamental problems associated with audio sonar simulation is a determination of what it is one has to simulate, and then a measure of the quantitative aspects of what it is that is being simulated. To rely on the query: "How does it sound to you?" is filled with danger. Perhaps a better way is to obtain at-sea recordings under calibrated conditions, then analyze these with an audio spectrum analyzer, and later use the same instrument to verify the authenticity of the simulated signals. Naturally, one must proceed with care, and limit himself to evaluating a limited number of signals at one time. For example, if the analyzer is used to ensure that the simulation equipment duplicates the aural response of an audio source taken singly, and then a similar procedure is employed to duplicate other audio sources, the probability that, when all sources are coupled together, the overall results; i.e., the sum of all aural contributors, will also be realistic and require relatively little adjustment. In this respect, it is imperative that the spectrum analyzer employed is not only adequate for the task, but that the operator of the analyzer be sufficiently knowledgeable of the limitations and virtues of this test equipment. The audio spectrum analyzer is an extremely valuable piece of test equipment in sonar audio simulation, when employed judiciously.

One frequently must consider the gains and losses associated with simulation versus stimulation in the audio sonar area. If one were to use portions of operational equipment in the training device, and inject simulated signals into such equipment, the question remains as to where in the system is it most advantageous to inject such signals. Obviously, a scheme where simulated signals are generated with the correct temporal and

spatial relationships, and then fed into the "front-end" (hydrophones) of a sonar may require hundreds of audio channels. Such a scheme, while not necessarily unworkable, is somewhat impracticable.

In many cases, total simulation of the operational equipment audio processing channels is most desirable. After all, what is the ultimate goal? It is to realistically provide audio signals at some listening devices which appear to emanate from a real world. It is not important what means are used to generate these signals; only, the end result is of importance. Hence, in the ideal case, one simply requires a black box called audio simulation and a headset. This black box need not necessarily contain any components associated with the actual operational gear being simulated. Consider an audio channel where perhaps ten separate processing operations modify and act upon the signal between the hydrophones and the listening device. For training device purposes, the place to analyze the signals initially, is immediately before the listening device, as this may be where the desired signals require the least complexity in simulation.

Early attempts at training devices relied heavily upon the use of at-sea recordings, mostly on magnetic tape. While these were as realistic as the recording situation and equipment quality would allow, these techniques suffered from serious drawbacks, in that they were "canned" problems. For an initial and basic familiarization with sonar audio they may have been sufficient, however, the student generally could not exercise his controls, e.g., pulse width, operating mode, etc., as the recordings were unique to a specific set of sonar settings and environment. The student could at best simply listen.

Subsequent developments in audio sonar simulation involved analog techniques. A conglomeration of pulse generators, oscillators, noise generators and timing circuits would individually generate the various signals required for the particular bandpass characteristics of the sonar being simulated. Naturally, the broader the bandpass, the more complex the sonar and range of environmental conditions considered, the more outlandish the assortment of individual generators required. Figure 1 represents a typical simulation scheme of this type. Each line spectra of interest required a separate oscillator, sometimes variable in frequency. These were summed with various noise generators to provide the required signal at the earphones.

The audio simulation problem can become quite severe if one is concerned about obtaining realism. Effects such as own-ship noise, sea-state, target radiated noise, biological noise, diurnal effects, machinery noise, etc., may be significant, with associated requirements for simulation. Figure 2 shows the aural responses associated with a bottlenose porpoise within bandpass limitations of a particular sonar under consideration for a training device. It is apparent that this single object contributes heavily to the required simulation signals. Then, when one adds the requirements, resulting from additional noise contributors, the problem rapidly becomes monstrous.

Further progressive developments in sonar audio simulation involves using analog generators, as shown in figure 1. However, the timing circuitry responsible for synchronizing the signals to a real-life situation was replaced by digital signals from a central master processor. This technique was effectively used in the simulation of the AN/SQS-23 sonar in Device 14A2, Surface Ship ASW Attack Trainer.

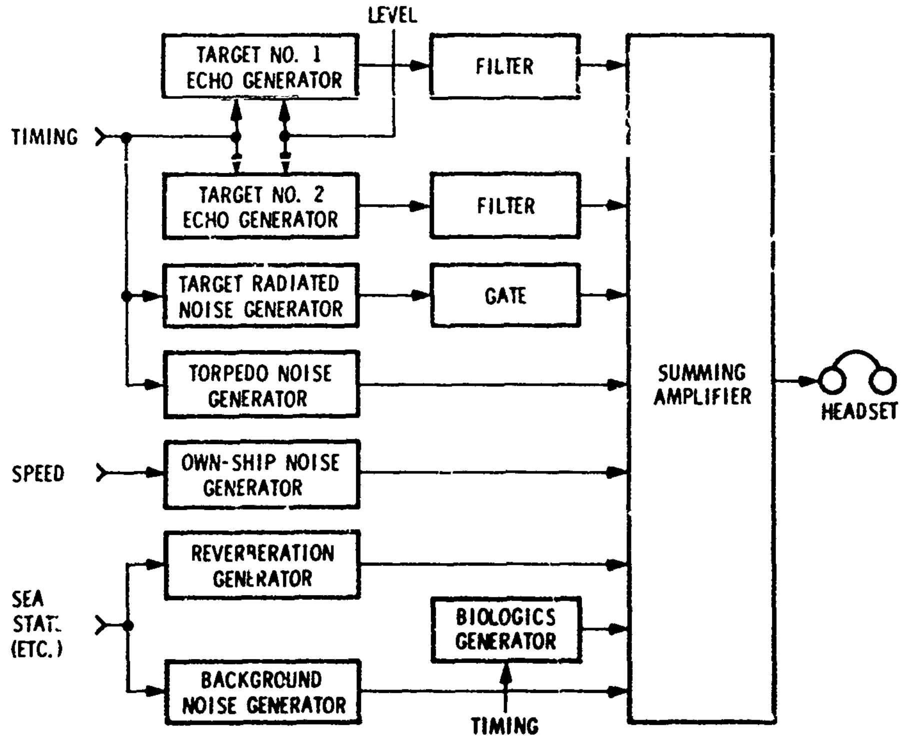

Figure 1. Analog Sonar Audio Simulation Block Diagram

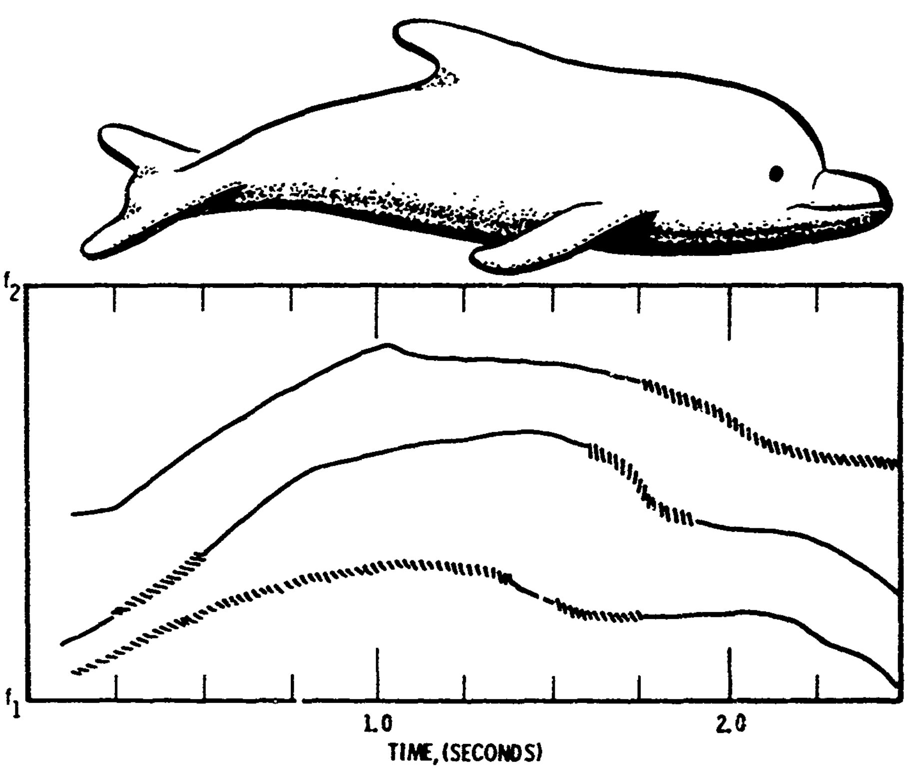

Figure 2. Aural Response of Bottlenose Porpoise

During the recent development of Device 14E19, Basic Operator/Team Trainer for the AN/SQS-26CX Sonar, additional breakthroughs in sonar audio simulation were successfully developed. This is the first system wherein sonar audio is generated by digital techniques. Figure 3 is a simplified block diagram of this approach. A sine-wave function is stored in computer memory in tabular form. Based upon the spectral sine components required at a particular time, this table is sampled at a rate corresponding to the frequency to be generated, and the results are held between sampling times in a register. Typically ten samples per cycle are obtained. Sampling times are in the order of approximately a microsecond. Additional spectral components are generated in the same fashion by time-sharing during the interval between sample times for other spectral components. In this particular training device, some 30 spectral components are generated simultaneously by such techniques. The sampled-and-stored output is then applied to a filter so as to remove higher order harmonics resulting from the sampling frequency. Audio signals of broad-band noise type character are also generated digitally by pseudo random techniques. A stepped sawtooth counter provides higher order harmonics associated with certain aural sources such as torpedoes and screws. The spectral line components and the noise signals are summed, filtered, and applied to headphones. The model employed for Device 14E19 considers audio signals resulting from own-ship, surface support units, submarines, torpedoes, sea-state, bottom, volume and surface reverberations, whales, porpoise, shrimp, pinnacles, ice and kelpbeds, which are of interest within the passband characteristics of the operational AN/SQS-26CX sonar. These signals are synchronized with their video counterparts in both time and space, resulting in extremely realistic simulation.

Generation of audio signals by purely digital techniques is not restricted to sonar simulation, but may be extended to other related disciplines. The beauty of such techniques is that the reliability is outstanding and the system is extremely flexible to future change within the constraints of the initial design, as virtually no hardware is involved. Also, accuracy problems resulting from drift and aging of analog circuitry are non-existent.

The art of audio sonar simulation has witnessed tremendous advances in the last decade. It is interesting to speculate about what technological advances the next decade will bring.

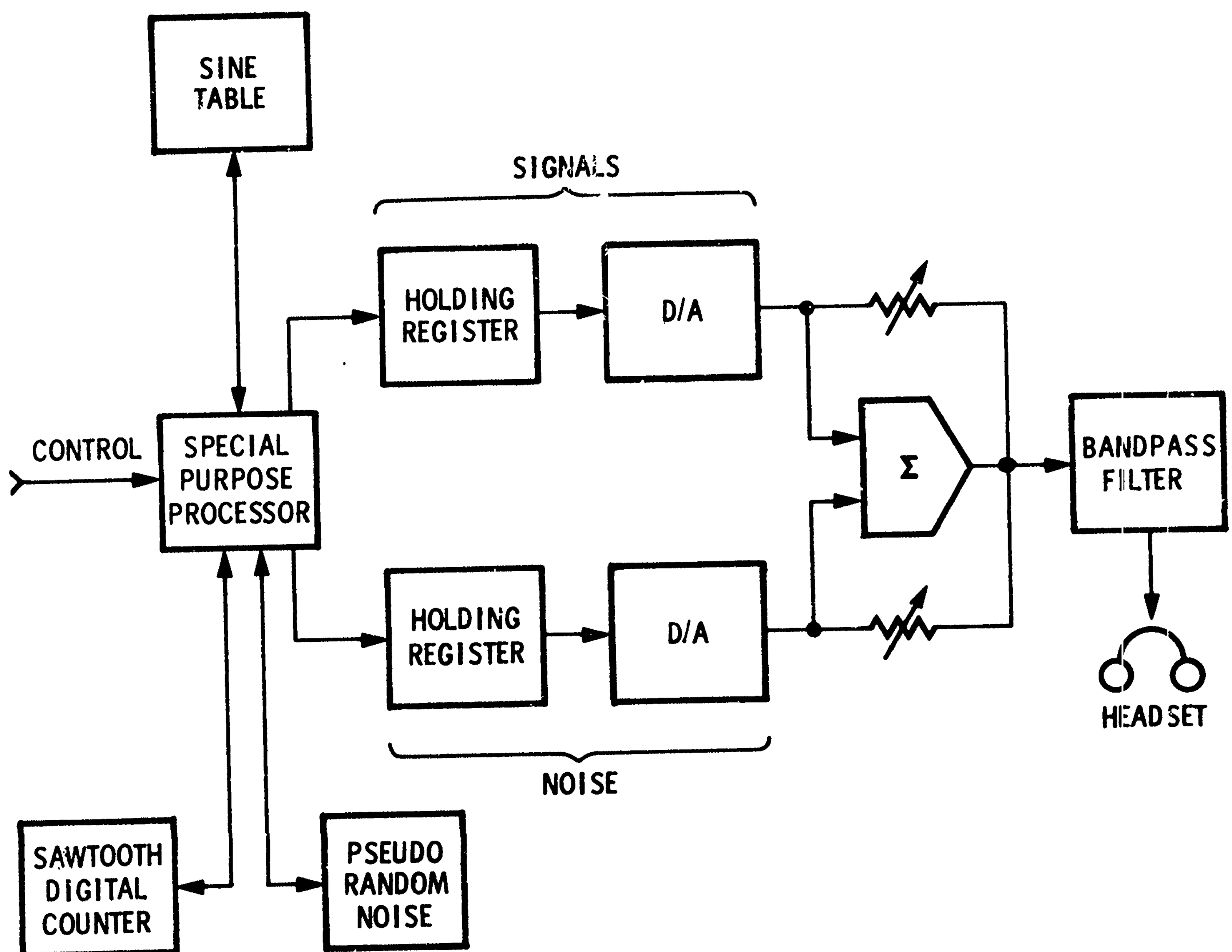

Figure 3. Digital Sonar Audio Simulation Block Diagram

MULTIPLE OSCILLOSCOPE TRACE GENERATION FOR ANALOG COMPUTERS

MESSRS. KLAUS W. LINDENBERG, Assistant Professor of Engineering
and
PAUL E. SPEH, Senior Analog Computer Programer .
College of Engineering, Florida Technological University, Orlando, Florida

In many training and simulation situations, which utilize analog computers, it is desirable to have the option of viewing multiple, independent displays on a single cathode ray tube. However, most small analog computers are equipped only with a single trace capability oscilloscope and the added expense of purchasing a multitrace unit often cannot be justified. Furthermore, general purpose multitrace oscilloscopes are limited in the number of traces which can be produced and do not usually permit one to generate simultaneous X-Y and X-t displays.

At Florida Technological University the analog computer system consists of an Applied Dynamics Corp. model AD-5 computer equipped with four remote, time shared terminals, each of which is equipped with a single trace storage oscilloscope for display. While investigating a manual tracking problem we found that at least three independent traces were required at each of the four terminals. Therefore, a multitrace display system operating under computer control and utilizing the existing single trace oscilloscopes was designed. The main design requirements for the system were first, that it provide maximum applications flexibility since the computer is used by a number of individuals for research as well as instruction. Second, the tracking problem being studied called for a minimum of three traces, each to be independent of the others with respect to amplitude, position, and timing. Third, the limited computing power of the machine necessitated a design which would not decrease the machine's computing capability significantly. The figure depicts the system which was finally chosen. This system is completely under machine control and requires neither external circuitry nor machine integrators.

The six input signals, which can be either internally generated by the machine or externally generated, are brought to the inputs of six individual summing amplifiers, as shown in section 1 of figure 1. The potentiometer at the second input of each amplifier is used as a positioning control.

In section 2 the outputs of these amplifiers lead to a device peculiar to the AD-5 computer, the switching amplifer. The switching amplifier is a standard summer amplifier whose inputs can be switched off independently by a standard TTL logic signal. Such a signal can be generated elsewhere in the computer.

The switching amplifiers in section 3 merely collect the various switched inputs and route them to the appropriate oscilloscope axes.

In principle the amplifiers in sections 2 & 3 of the schematic could be consolidated into a single amplifier having four switched inputs.

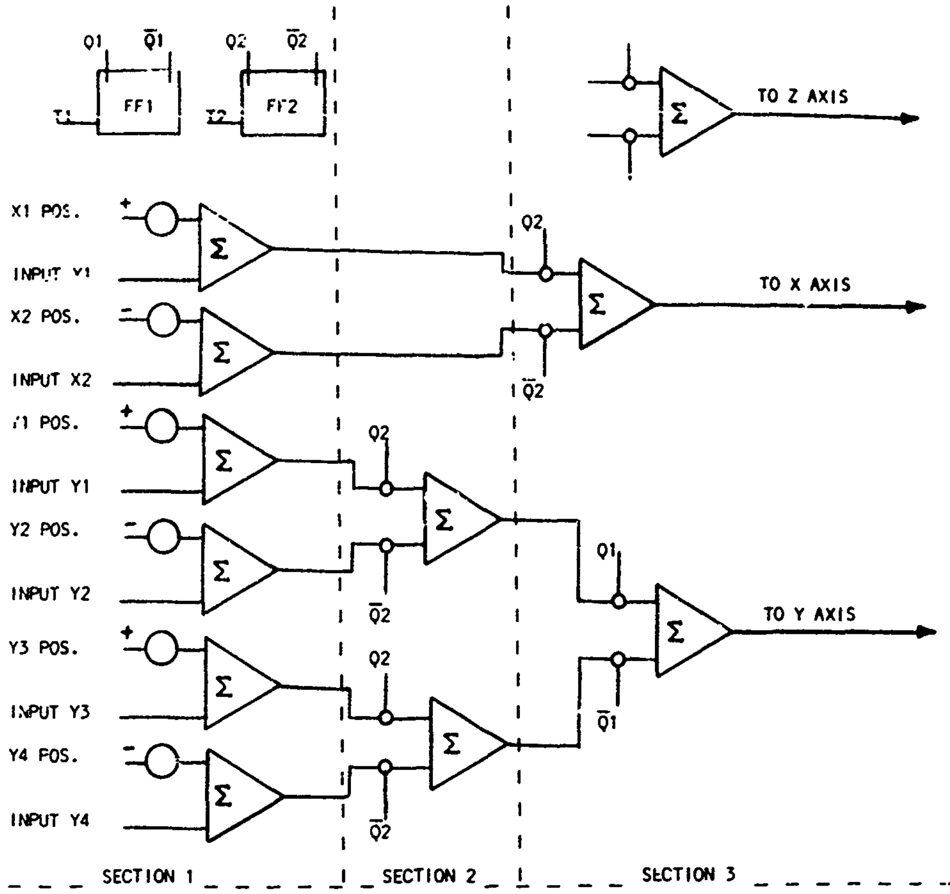

Figure 1. Schematic of the Multiple Trace Generating System

At present, the switching signals are derived from the timing generator of the computer, however, they could be externally generated or program controlled. The flip-flops shown in section 1 of the figure condition the timing signals to the required TTL levels.

It can be seen from the figure that the maximum number of signals that can be displayed depends only upon the number of available inputs on the switched amplifiers.

Now in use, the display control system has proved to be an invaluable aid in generating displays which were previously unattainable with the equipment on hand. At present it is possible to show simultaneously an X-Y plot, a waveform plotted versus time, and an illuminated spot showing the position of a joystick controller.

Although only three signals are presently being displayed, the system is capable of generating quite a few more. The two main limitations on the ultimate number of displays so generated are the number of switching amplifiers available and the resolution of the oscilloscope screen.

The possible applications of this system are only limited by the imagination of the user. Current applications at Florida Technological University include such diverse areas as speech sound analysis, ecological limit cycle simulations, and human operator performance studies.

ELECTROMAGNETIC COMPATIBILITY OF TRAINING DEVICES

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INTRODUCTION

Whenever a training device containing electronic equipments is operated in its intended operational environment, at designed levels, without degradation due to interference, it is called electromagnetically compatible. This paper will give some background history on interference specifications, their application to training devices, several problems that have occurred, present status of trainer EMC, and a forecast of what contractors may expect in the EMC (Electromagnetic Compatibility) area in the future.

BACKGROUND OF INTERFERENCE SPECIFICATIONS

The earliest electromagnetic interference specifications were written 25 years ago to control interference to voice communication receivers from aircraft electrical systems. In 1954, the Bureau of Ships, made revision to a draft of MIL-STD 225 and issued it as MIL-I-16910. The "C" version of this specification was dated 26 October 1964 and contained the radiated and conducted interference limits and test procedures to be used for Navy shore and shipboard electronic equipments. The Navy Bureau of Aeronautics generated another version of the proposed MIL-STD-225 which resulted in MIL-I-6181. In August of 1968, MIL-STD-461, "Electromagnetic Interference Characteristics Requirements for Equipment" was issued and superseded the general Army, Navy and Air Force interference specifications, including MIL-I-16910C which the Naval Training Device Center was using. The MIL-STD was a coordinated document containing interference test limits. The test procedures were documented in MIL-STD-462, "Electromagnetic Interference Characteristics, Measurement of," dated 31 July 1967. These Standards were meant to be used as a source for tailoring the interference requirements to meet the needs of the equipments being procured.

NAVTRADEVCEN INTERFERENCE CONTROL BACKGROUND

The Naval Training Device Center EMI philosophy prior to 1968 was to reference MIL-I-16910 directly in the trainer specification or indirectly through MIL-T-23991. Testing was occasionally performed. In 1968 MIL-STD-461 requirements began appearing in major training device specifications. The Electromagnetic Interference Control Plans became part of contractor submitted documentation. Some testing was required.

In an effort to avoid some of the less-than-desirable practices in cabling and grounding viewed in the field, MIL-T-23991C, dated October 1968, had new sections devoted to these areas. Additionally, the Air Force Handbook on Electromagnetic Compatibility was referenced as a design guide for meeting the electromagnetic interference suppression requirements appearing in the trainer specifications.

The detail specifications began having paragraphs requiring that elevated floor systems be incorporated into the overall grounding system, using MIL-STD-1310, "Shipboard Bonding and Grounding Requirements for Electromagnetic Compatibility" as a guide in the electrical bonding area. Crosstalk and signal-to-noise ratio requirements for audio communications systems were also included to eliminate these problems in future systems.

PAST PROBLEMS

A survey of recorded past interference problems revealed that trainers have not been a source of interference to other systems. Training devices also have been relatively free of being troubled by electromagnetic wave radiating systems (radar, TV). Interference that has been troublesome from external sources has usually entered the training device through the prime power leads. These have been of a transient nature such as large loads either going on or off the line and lightning effects.

It was revealing, however, to find that the majority of interference problems are self-induced. The following five cases are a small sampling of self-incompatibilities that have occurred:

Case 1 - An interference problem on a Sonar Tactics Trainer that required significant time and manpower to remedy was reported, with slight changes, as:
The 400 Hz and 60 Hz interference problems in the Sonar Systems have reached an unsatisfactory level. The major source interference appears to be topside in the cabling. One of the sonar receiving sets has 400 Hz interference internally as well. The interference problem from the cables appears in the audio circuits and also on the Scan Presentation. This interference appears at certain bearings only and these bearings can be made to change by rearranging the cables. It is felt that the following list of discrepancies have contributed to this problem:

Intermixing of signal cables and 400 Hz and 60 Hz power cables in the cable runs

Failure to shield signal cables and power cables sufficiently

Many of the cables are too long and have been doubled back or coiled rather than cut to the proper length.

The grounding system has in many cases been wired such that ground loops are possible.

After the installation of a Torpedo Modification, the interference seemed to increase. It is felt that the installation crew disturbed the cable runs under the Attack Center.

Case 2 - The following problem is associated with a Weapon System Trainer located in a van:

At present there is an intolerable amount of feed-through from the pilot's ICS to the sonar ICS and vice versa. When independent hops are given, there is confusion when trainees start to talk on both ends at the same time. Maintenance intercom also feeds into the trainees' ICS system. Background noise when selector buttons are pushed is too loud.

Case 3 - Some discrepancies on a Flight Portion of a Weapon Systems Trainer read as follows:

a. ICS too noisy
b. UHF Comm (Main) noisy (intermittent)
c. Computer stops for unknown reason, requires master clear and start to resume operation
d. Computer stops, program is destroyed, requires re-load of program to resume operation.

Case 4 - Another problem on an Operational Flight Trainer:

Random erroneous signals are inputed to the computer whenever the air compressor in the trainee station cycles on or off.

Case 5 - A problem on a Radar/MAD Trainer

Interference from a 60 to 400 Hz frequency converter used in the system was causing noise to appear on the radar land-mass displays.

Most of the above problems have been taken care of, leading us to the present status of EMC at the Naval Training Device Center.

PRESENT STATUS

EMC field problems of the Case 1 magnitude do not currently exist. Field problems are becoming more scarce due to improved interference design practices and the contractor's awareness and ability to locate and rectify them prior to device acceptance. The "sore thumb" that needs medication now is the reduction of noise and crosstalk in the trainer audio systems.

GROUNDING, BONDING AND CABLING

Grounding systems are being improved. Elevated floors of the bolted stringer type are being used as an essential part of the trainer grounding systems.

In the area of electrical bonding practices, some contractors now have standard practices and procedures that are documented as company standards and have been found to be satisfactory. Not all contractors have had the opportunity to establish such practices and such matters are left to the individual expertise of the mechanical or electrical designers at the time of the particular trainer design.

An area which has been vastly improved in the past three years is cable categorization and separation. The planned routing and grouping of power and signal cables, according to interference producing capability and susceptibility to cable coupled interference in conjunction with improved grounding system, has probably done more for solving difficult problems than any other single item. Cabling installations are being designed in a fashion analogous to laying out the signal connections on a multilayer printed circuit board.

INSTALLATION SITES

Installation sites are studied in an effort to define risk areas to the local environment due to the probable emissions from the trainer and the risk areas of the environment to the trainer. As new buildings are planned to house training devices, electrical prints are reviewed to ensure that the grounding systems will be satisfactory for electronic equipment grounding and lightning protection.

MIL-STD-461 INPUTS

From a MIL-STD-461 viewpoint, the major training devices (that are closed systems (non-antenna type)) usually have three design requirements in the specification to control susceptibility due to transients on the prime power lines, conducted emissions being generated by the trainer and going out on the prime power lines and radiated emissions from the training system. Commercial off-the-shelf equipments such as computers are not required to be shielded. However, there is concern for the radiated emissions from the cables since they may become fairly efficient radiators and the location of many of the trainers are near operational equipments. The current specification input often has the following appearance:

> <u>Electromagnetic Interference Suppression</u>
> All electronic equipment other than off-the-shelf equipment to be furnished by the contractor shall be designed to meet the following requirements of Class 1C equipment listed in table 2 of Mil-Std-461: CE03, RE02, and CS06. Commercial off-the-shelf equipment shall be modified, if necessary, to meet the requirements of CS06 for power inputs and RE02 for cabling external to the equipment enclosures.

TESTING

Experience has indicated that the cost-effectiveness of testing to the electromagnetic interference suppression requirements is a variable determined by the installation environment. The current philosophy is to do as little testing as possible. Testing may be limited to checking the grounding system to ensure separation of the various categories of grounds and the electrical resistance across electrical bonding joints. Interference in the intercoms is and has been such a nuisance that it has been singled out for special attention. A general specification for communication systems for training devices (MIL-C-29025 TD) was issued 14 September 1971.

FORECAST FOR THE FUTURE

To extinguish the intercom interference fire, it is expected that intercom systems will be required, as a minimum, to meet the background noise, signal-to-noise and crosstalk levels prior to device acceptance. It is expected that a document on grounding and bonding will be written to standardize the techniques and the hardware for training device systems. The EMI Control Plan will be required to be submitted on major training devices. Its use is expected to diminish over the next five years as the Center's contractors become experienced in interference control design.

MIL-STD-461 is undergoing a change to make it more effective. It is expected that NAVTRADEVCEN specification will contain the "design to meet" requirement unless installation environment necessitates the "shall meet" requirement. When the "shall meet" clause is used, the specification will also have testing requirements.

Facility requirements will continue to be viewed with the purpose of ensuring that the training system and the facility will have a high probability of being compatible. Areas of interest will be existing cabling, grounding systems, power distribution and interference risk areas from transmitting systems.

SUMMARY

The Naval Training Device Center has had its share of interference problems, particularly in the area of self compatibility. Although the random type problems are being eliminated through improved electrical grounding and cabling techniques, power line transient and, particularly, audio communication interference problems continue to exist. Efforts are being directed to ensure their non-reoccurrence through improved specification requirements, design monitoring and contractor education.

SESSION V

Thursday, 17 February 1972

Chairman: Mr. Victor G. Hajek
Head, Air-Warfare Department (ASW/Environmental)
Naval Training Device Center

NEEDED: A STRATEGY FOR THE APPLICATION OF SIMULATION IN THE CURRICULA OF PROPOSED TRAINING SYSTEMS

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Land/Sea Trainers Applications Division
Naval Training Device Center

During the past year Naval Training Device Center personnel have been reviewing curricular materials which have established how the major Navy training simulators are used. This experience has convinced me that simulators are making a significant contribution to Navy training. Yet as I have studied simulator use patterns, it has become apparent that modern simulation technology has provided training capabilities that have yet to be absorbed into the working curricula of training activities. Tradition, rather than analysis, remains the prime rationale for designating which training objectives should be accomplished in simulators.

The study of simulator curricula is a part of a continuing device utilization measurement program, established under OPNAV Instruction 10171.4A. Within this program we are attempting to identify the purposes for which training devices are being used, the instructional methods being employed, and the relative cost of these various employment patterns.

There are various reasons for collecting and displaying historical data on how simulators are employed in Navy training. One of the reasons is to build a base of data and techniques for use in projecting future utilization patterns and cost on both existing simulators and proposed simulators - information that will be useful in trade-off studies for justifying the continued use of existing simulators and for justifying the development of major new simulators.

The curriculum, perhaps more than any other factor, determines the use pattern of a major device. This may be obvious to many people. But, when you are involved in the development of simulators, at the Naval Training Device Center, or as a contractor, you are aware of the important capabilities of the simulators, and frequently assume that because these capabilities exist, they will be used. This is not true. The configuration of the simulator sets certain limits on the use patterns, but it is the curriculum that determines how the simulator is actually employed.

Because of the importance of the curricula in establishing the utility of major simulators, certain individuals at the Naval Training Device Center are providing fleet training programs with technical assistance in the development of curricula materials. Either as in-house projects, or with the aid of contractors, Education Specialists, at the Center, are helping to develop detailed syllabi, and instructor handbooks containing exercise plans designed to meet fleet training objectives.

With a new awareness of factors, that determine how a simulator will actually be used, it has become evident that training devices should not be conceived merely as simulators of operational systems. Simulators should also be preceived as elements in the larger training system. In turn, the curricula for simulators must be viewed as elements in the curricula of larger training systems.

Figure 1, a simple system diagram, identifies major elements in a training system. It makes visible certain decisions that should be made during the design of a simulator and the development of the curriculum for the use of the simulator. This is a theoretical system concept. I am not suggesting that it is a model of what actually takes place in the design or functioning of training systems.

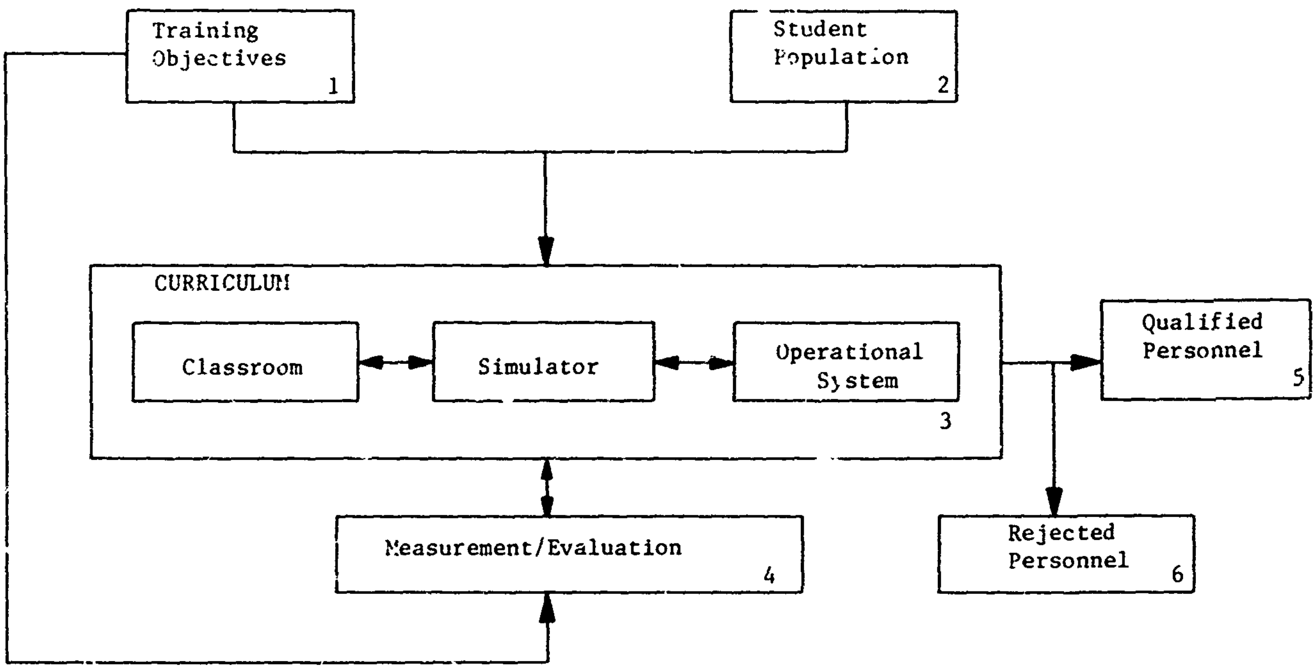

Figure 1. Training System

Based on an estimate of the individual and team skills required for the operation of a new weapon system, training objectives (element 1) are specified. Characteristics of personnel to be designated as operators of the system (element 2) are also designated. A curriculum (element 3) is planned, which is capable of training the specified personnel, to meet the training objectives. One of the critical functions of the curriculum is to designate a mix of training resources. The curriculum should designate which individual and team skills are to be achieved in the classroom, which are to be achieved in various forms of simulators, and which are to be learned in the operational system. It should also specify what level of skill in each instance is to be attained in the various instructional environments.

A measurement and evaluation program (element 4), should monitor student and team behavior, ensuring that prerequisite skills are learned before advanced skills are attempted. A student or team should be released from the system only after the training objectives (element 5) have been achieved or when it is projected that the students will not be able to meet the objectives within acceptable time or dollar limits established within the training system.

When the basic mix of resources within the curriculum of a new training system is specified, prior to the development of training hardware, the training devices or simulators can be configured to perform the specified role designated for simulators in the overall training system. This role would not be just something that happens without thought. It would be based on a

set of carefully considered decisions concerning the role of simulation in the training system. The simulator would then be configured to ensure successful achievement of that role. The curriculum for the simulation would be responsive to that role. In addition, the utilization pattern of the simulator could be measured against that role.

A set of special competencies or techniques are required in designing a curriculum specifying the use of a training device as an element of a larger training system. Some of these techniques already exist in a usable form, others are in a primative state of development. See figure 2.

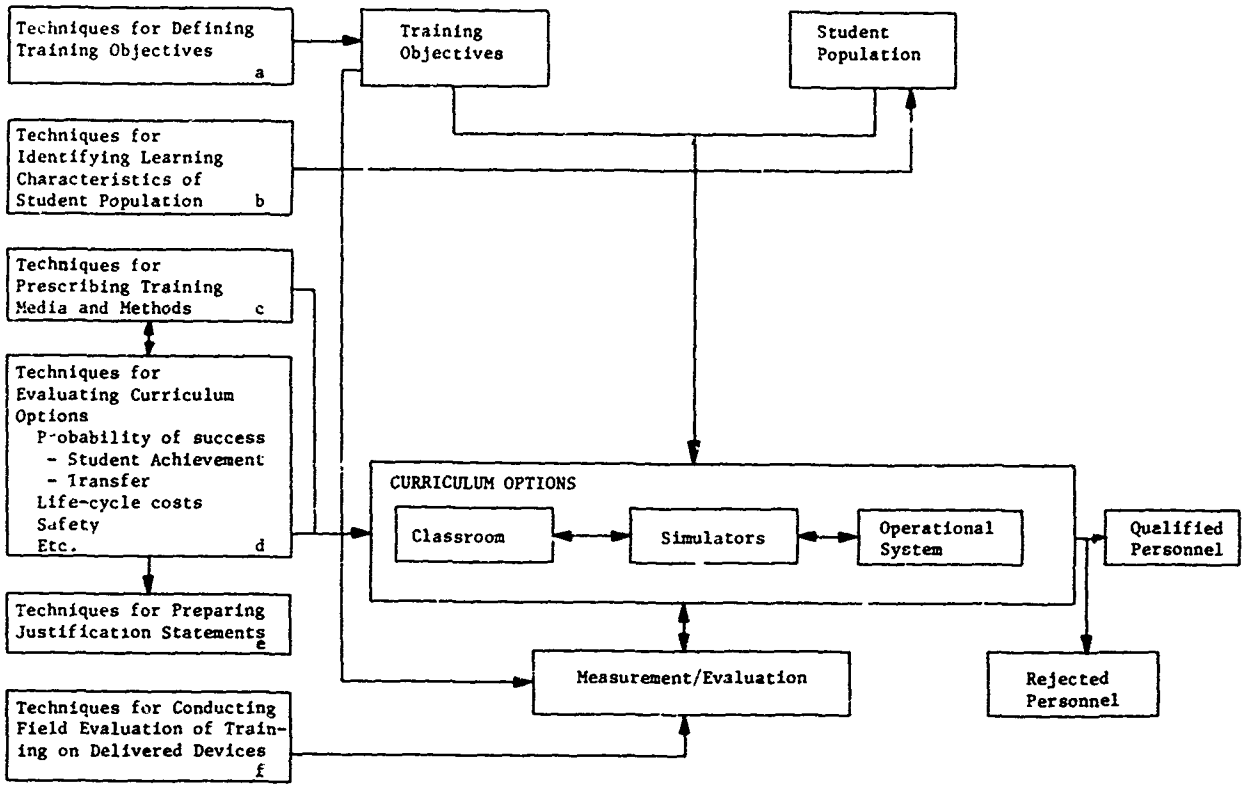

Figure 2. Techniques Required for Planning and Evaluating Training Systems

Techniques exist for defining training objectives (element a), as well as for identifying specific learning characteristics of a student population (element b).

However, we are a long way from having a set of strategies or methods for prescribing which forms of media, and which methods to use in achieving specified types of training objectives with various types of students (element c).

The curriculum designer has a role similar to a medical doctor in seeing a patient in his office. Just as the medical doctor diagnoses the condition of a sick patient and prescribes medication and therapy for the patient's recovery, the curriculum designer must diagnose the condition of a set of students, consider the skill building resources that can be brought to bear

on the problem, and then prescribe one or more ways that the students can achieve the desired skills. Each prescription should contain a specified mix of learning experiences, the classroom, various forms of simulation, and the operational system. This mix of resources can only be considered in the context of the training system.

Once two or more curricular options with specified mixes of training resources have been identified, the next step is to evaluate them and select one for implementation. To do this we need information that does not exist, or at least is not organized for easy use. Evaluation techniques (element d) should include a way of estimating the probability of success for a proposed training system, success in terms of student achievement. We need usable and accepted guidelines for projecting the extent of transfer of learning that will take place, from a specified training system, to an operational system. These problems of measurement and the projection of achievement and transfer are receiving increased emphasis at the Naval Training Device Center.

Considerable effort at the Naval Training Device Center has been spent in developing techniques for projecting life-cycle costs on proposed simulators, and on collecting historical operating cost data on existing devices. Usable techniques are available. We also have techniques for comparing the relative cost of conducting an exercise in the operational system and in the simulators. Through the use of these projections, cost of ownership for proposed simulators can be one of the factors used in trade-off studies leading to a decision concerning which segments of a training program should be conducted in simulators and which in the operational systems.

The evaluation of a trainer and its curriculum in terms of projected student achievement, transfer and cost per student graduate can, in many instances, be useful in justifying the continued support or development of a simulator before budget and program analysts at the Department of Navy and Department of Defense levels (element e).

After a simulator and its exercise plans have been developed, as an element within a training system, a field evaluation should be conducted to determine if the training objectives for the simulator are being achieved (element f). At the present time, other types of demonstrations are required. We require the contractor to demonstrate that the simulator meets engineering specifications, including performance, maintainability and reliability. As a part of the maintenance training courses, students are required to demonstrate their ability to properly maintain the simulators by solving a series of carefully selected problems on the trainer - demonstrating that the maintenance course objectives have been met. We need, now, techniques for demonstrating that the training device is meeting the training objectives for which it was built.

As previously stated, at the heart of the problem of how to employ a simulator in a training system is the problem of selecting a mix of training resources. Which objectives can and should be accomplished in simulators, which in the operational system. A related question is what level of skill should be achieved in the simulators, before proceeding to the operational system?

Table 1 depicts six different mixes of training resources, ways that simulators are being employed in training systems.

TABLE 1. THEORETICAL MIXES OF TRAINING RESOURCES FOR ACHIEVING LIMITED TRAINING OBJECTIVES

MIX NO.	CLASSROOM	SIMULATOR	OPERATIONAL SYSTEM
1	facts and knowledge	-	Familiarization Practice to Criterion* Certification
2	facts and knowledge	Familiarization	Practice to Criterion* Certification
3	facts and knowledge	Familiarization Initial Practice	Practice to Criterion* Certification
4	facts and knowledge	Familiarization Practice to Criterion*	Practice to Criterion Certification
5	facts and knowledge	Familiarization Practice to Criterion*	Certification
6	facts and knowledge	Familiarization Practice to Criterion* Certification	-

*x Successful performances

For example, mix number one is a common pattern in many training programs. The facts and knowledge aspects of specific skill are learned in the classroom. Familiarization, which involves an instructor demonstrating or guiding the student through the initial trials, is performed on the operational system. Practice to criterion and certification also take place on the operational system. Simulators are not used in this mix of training resources.

With mix number three, familiarization and initial practice occur in the simulator, and then additional practice to criterion and certification take place in the operational system. This pattern is frequently observed in trainer utilization programs.

Mix number four is a mix that is seldom observed. Familiarization takes place in the simulator, then the simulator is used for practicing the skill until criterion performance is achieved. This criterion may be defined as one errorless performance in the simulator, or perhaps, five consecutive errorless performances. Upon achieving criterion performance, the student or team proceeds to practice, as required, on the operational system, then passes the certification, or check hop, on the operational system.

Under certain circumstances mix number six is being used. All three phases are conducted in the simulator. This mix may be selected, when the skill or procedure to be practiced cannot be performed in the operational system, due to hazards or because targets, etc. cannot be obtained.

For what purposes should simulators be used? In what manner should they be employed? There are traditional answers to these questions. Yet, traditional answers result in the use of simulators primarily for the familiarization phase of a training program. We can build bigger and better simulators, but this does not guarantee that new patterns of use will result. The curricula for trainers must be innovative and must be developed with the same degree of professionalism used in the design of the simulator hardware.

We need to view a simulator as one element in a training system. We need to clearly identify the mix of training resources in this system, to identify the specific functions to be performed by the simulator. As the simulator is being developed we need to develop the detailed curriculum materials, and then train instructors in the use of these materials. And finally, we need to measure the utility of this package, simulators and curricula, in terms of student achievement and transfer of training, as specified in the training objectives.

TRADEOFF CRITERIA FOR SPECIFICATION OF PRIME OR SIMULATED COMPUTERS IN TRAINING DEVICES

MR. A. E. MERGY
Manager, Training Equipment Engineering,
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INTRODUCTION

Prior to the establishment of a simulator specification for a new system, a comprehensive analysis of the training requirements and the intended utilization environments must be accomplished in order to assure the training effectiveness of the resulting hardware design. Too frequently the exigencies of time and budgets result in shortcuts or guesstimates replacing the required analysis and planning. The result is an underestimate of the required training requirements and the functional performance capability of training equipment. Similarly, we tend to forget that each new weapon system and its integral subsystems must be significantly different in capability and performance, than its predecessor, in order to exist in today's restrictive and highly competitive defense budget environment. For a program to have survived requires, not only, a significant step function improvement, but also requires that the threat environment, in which it is to perform, must have achieved a similar increase in sophistication or complexity. Unfortunately, we have not been able to re-design the man to achieve step function increases in capability and performance. The logical alternative has been to imbed in almost every system highspeed computational elements to perform those logical and analytical functions, which man has found himself incapable to perform, in the increasingly more complex tactical environment. By design intent, each system's resultant utilization or employment is significantly different than its most similar predecessor. Similarly, the training requirements are significantly different. For the same reason that shortcuts are not taken in prime equipment design, shortcuts must not be taken in the analysis of training requirements upon which equipment specifications are to be based.

Properly conducted, these training requirement analyses will provide a baseline, which may identify a spectrum of hardware devices, with supporting training aids and media concepts, time-phased in implementation to support the overall training plan. It is at this point that the essential characteristics of hardware devices must be evaluated, not only, in terms of functional performance, but availability for and adaptability to the training program, and its curriculum requirements. Decisions must now be made on hardware solutions to the functional

performance requirements. Invariably, one of the most difficult hardware decisions to be made, when specifying a simulation device, is the tradeoff between utilization of the prime system computational elements and its related software, and the simulation of the prime system computer and its software.

PRIME VS SIMULATED COMPUTER TRADEOFF CRITERIA

The tradeoff process involved in selection of the hardware solution to a functional performance requirement is not a clean-cut process. Decision processes range from the highly objective, employing rigorous analytical techniques to the highly subjective substantiated only by human emotions. We have come to the conclusion that one of the main subjective reasons for using a prime computer in a trainer is the hope this would provide a more direct method of transferring software changes from the prime system to the trainer than if the computer were simulated. When we talk about using the prime system in the trainer we are implicitly including the prime software. No doubt bitter experience with prime system software change control in the past justifies looking for drastic solutions to the problem as it affects the trainer. Fortunately the software concern is not the only criteria for specification of prime equipment. During the decision process this fear becomes only a subset of four major criteria groups which emerge as cornerstones for the ultimate decision. For tradeoff convenience these criteria groupings are categorized in figure 1 in terms of the trainer's utilization, time constraints, technical considerations, and risks.

<u>UTILIZATION RELATED CRITERIA</u>

- o End Use Intent
- o Colateral Use Intent

<u>TIME RELATED CRITERIA</u>

- o Training Need Date
- o Equipment Availability
- o Software Availability
- o Flexibility for Change

<u>TECHNICALLY RELATED CRITERIA</u>

- o Technical Approach
- o Fidelity
- o Cost

<u>RISK RELATED CRITERIA</u>

- o Contracting Risk
- o Supportability

Tradeoff Criteria Grouping

Figure 1. Criteria Groupings

If each criteria group is rationally analyzed and evaluated a pattern emerges that can provide insight into the prime vs simulated computer-decision process. Some typical tradeoff processes are provided as examples of situations that contribute to the final decision on the hardware configuration.

OPERATIONAL EQUIPMENT. In some cases, an operational system may be used in total as its own training device, which settles the question of the prime computer. For example, in large ground-based or shipborne weapon systems there is a great advantage to having the ability to input simulated inputs into the sensors, so that training can be accomplished in the operational environment. Typically, such a capability is desired for tactics training, and for refresher rather than basic training. The simulated inputs can be a very desirable alternate to flying expensive real raids against the system. If the original prime system specifications cover this type of capability, then the system will be designed with the necessary added computer speed, memory capacity, computer programs, peripheral devices, and special sensor simulation hardware to accomplish it. If the system is not originally designed, with this capability included, it may be possible to add on the necessary storage, input/output devices, etc. at a later time. The operational system is thus itself a training device, which obviously requires the total utilization of the prime computer.

SIMULATED OPERATIONAL EQUIPMENT. The simulation of an operational system presents a less clear decision-process on utilization of the prime computer. Because this class of simulator typically has pre-formulated data on the characteristics of the trainer world; e.g., target and emitter characteristics, navigational data, range and bearing relationships, etc., much of the prime computer capacity and software routines are not fully utilized, or even needed. This partial utilization of computational capacity then becomes both an equipment cost and technical penalty associated with the device. This potential excess computational capacity then presents an interesting anomaly. If a decision were made to utilize this capability then the existing prime software must be modified to include trainer peculiar routines. This defeats one of the implicit reasons for prime computer utilization--use of prime software.

A more subtle tradeoff is presented when a collateral utilization of the trainer is implicitly intended. This occurs, for example, when modification of prime equipment software is a major operational or a post engineering development concern. This use in technical evolution of prime equipment capabilities is a trainer utilization that is frequently overlooked, but provides a weighting factor in favor of the prime computer system.

A similar hidden objective, that is frequently satisfied by a trainer, is the evolution or refinement of operational tactics. Although, not normally encouraged, a totally simulated operational computer and software system does provide a software modification capability to rapidly evaluate tactics against new threats. This capability is expecially valuable in the simulation of EW environments or evaluation/assessment of actual missions.

MAINTENANCE TRAINERS. Often overlooked in the tradeoffs of prime and simulated computer equipment is the maintenance trainer, where normal inclination has tended toward almost predetermined use of prime hardware. Often this has resulted from an unclear definition of the trainer's major intended use. The use of a total system in a "hot mockup" configuration is the frequent offender, when the intended system use might only be to train personnel, on built-in-test accessing and display interpretation. Realistically conducted tradeoffs invariably tend toward simulation of the prime computer for built-in-test and system fault insertion simulation.

TIME CRITERIA VS COMPUTER DECISION

Assuming that a detailed training plan has been postulated, training need dates usually dictate trainers ahead of(ideal), or at least concurrent (acceptable), with system delivery, or at the very worst not more than three months subsequent. Unfortunately, these time requirements are not always met. The principal constraint is the necessity for the near concurrent development of the prime system and its trainer.

What are the effects of this design concurrency upon the computer tradeoff decision? Let us now assume it appears to make sense to use the prime system computer in the trainer, at least, from the technical standpoint, and see what effect the prime system and trainer development schedules might have on the decision.

One factor is change control. If the trainer schedule is nearly concurrent, with that of the prime system, the problem of keeping the trainer and prime system programs looking alike is most severe because of the high rate of changes. This rate of change would appear to reinforce the decision to use the prime system computer in the trainer. But, invariably the computer hardware is a developmental model along with the rest of the prime system. The computer availability, for use in checking out the software, and the hardware interfaces in the prime system and trainer can become of much greater concern than the configuration problem. Even if it appears feasible to acquire an early model of the computer into the trainer, for checkout purposes, there is bound to be a very high risk. First models have bugs, suffer from documentation inadequacies, and incur reliability problems until the basic design has accumulated a large amount of operating time. Considering that the checkout schedules of the trainer have a higher order effect upon total costs, than change control, it becomes very questionabl whether one should ever risk a developmental computer in a trainer.

However, these problems can be circumvented to a large extent by an alternate approach. The main benefit gained by specifying the prime computer in the trainer is the carryover of the programs, not the hardware. It follows that an ideal solution would be to use an entirely different off-the-shelf computer in the trainer, but retain the ability to translate the prime system programs into the language of the trainer computer. This approach has been quite successfully implemented in recent complex simulators such as Devices 15C8, 15C8A, 15C9, and 15C9A.

TECHNICAL CRITERIA VS COMPUTER DECISION

Attempting to interface a prime system computer with a trainer can involve severe technical problems. Since, by their nature, these problems are subtle and complex they cannot be discussed very thoroughly in the paper. However, at least a few highlights are worth presenting. The objective will be not to advance any particular technical theory or methodology. Instead, emphasized will be the fact that, although the role of a computer and its programs in a system may at times appear to be straightforward, there is an excellent chance that the involvement is much more intricate than it appears to be. This fact may help caution us to be wary of innocently imposing design requirements, which contain hidden traps.

It is dangerous to underestimate the complexity of the computer's role in a prime system when considering transplanting the computer into a trainer. On the other hand, particularly, because of the difficulties involved in maintaining sofware change control, between the trainer and the prime system, there is good justification for attempting to use the same software in the prime system and

the trainer. The use of a trainer integral software translation approach offers considerable promise of solving a good part of the problem without incurring many of the risks, particularly, when the trainer and prime systems development heavily overlap.

One of the principal characteristics of the computer in a prime system is its role as a loop closer. In fact, a programable digital computer has the advantage over an analog computer in that it can be shared so as to close several loops simultaneously. This immediately begins to suffest that in a complex weapons system the computer may become imbedded in the system in a complicated manner. To start with a simple situation, figure 2a represents a familiar loop. This is most significant to the user, since in addition to himself, and the computer it involves the equipment, which normally occupies all of his attention. Disregarding any other factors, this makes it an ideal loop to transplant from the prime system to the trainer.

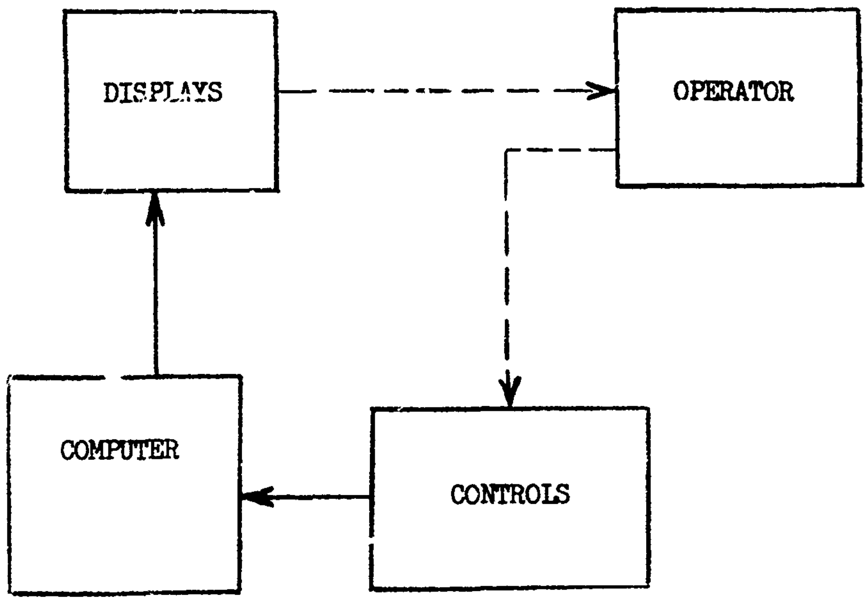

Figure 2a. Simple Loop Through the Operator

The problems start coming in from other loops, which are largely submerged. Figure 2b represents a simplified diagram of such a loop. The box marked "A" in the figure receives signals from the sensors (several kinds), performs some hard-wired functions, and passes the data to the computer for further processing. The loop continues with display of the processed data to the operator, who makes decisions, based on what he sees, and hears, and returns controls to the computer. The computer then sends signals to the box marked "B", which generates control signals for the receivers.

If the prime computer is used in the trainer, simulated data identical in certain specific respects to the data generated by box "A" in the actual system must be fed into the computer. The exact characteristics of this data must be known in order to provide adequate realism to the operator. These characteristics may include pulse repetition rates, pulse widths, frequencies, and the like. Moreover, it is important to know what these parameters really are in the system, as opposed to the design objectives contained in the original prime system specification. The difference between these stated requirements, and the performance achieved, can represent a considerable difference in the cost of

simulating the interface and resultant trainer fidelity. At the output of the computer to box "B" another situation exists. Although, in the trainer there is really no physical box "B" to control the computer must continued to stupidly send out control signals anyway, as it was programed. Again, this signal interface must be understood precisely, if one is to know how much of it can be ignored, and also know how to process the rest of it into a form suitable to send back through the simulated sensor and box "A". This assumes that prime hardware would not be used to simulate boxes "A" and "B," and the sensors, because simulating them in a trainer computer, with some added special hardware is generally cost-effective. However, as this discussion indicates, without adequate information on the interface requirements, there is a technical advantage in leaving the prime computer out of the trainer, and simulating the prime computer and its software by trainer peculiar software.

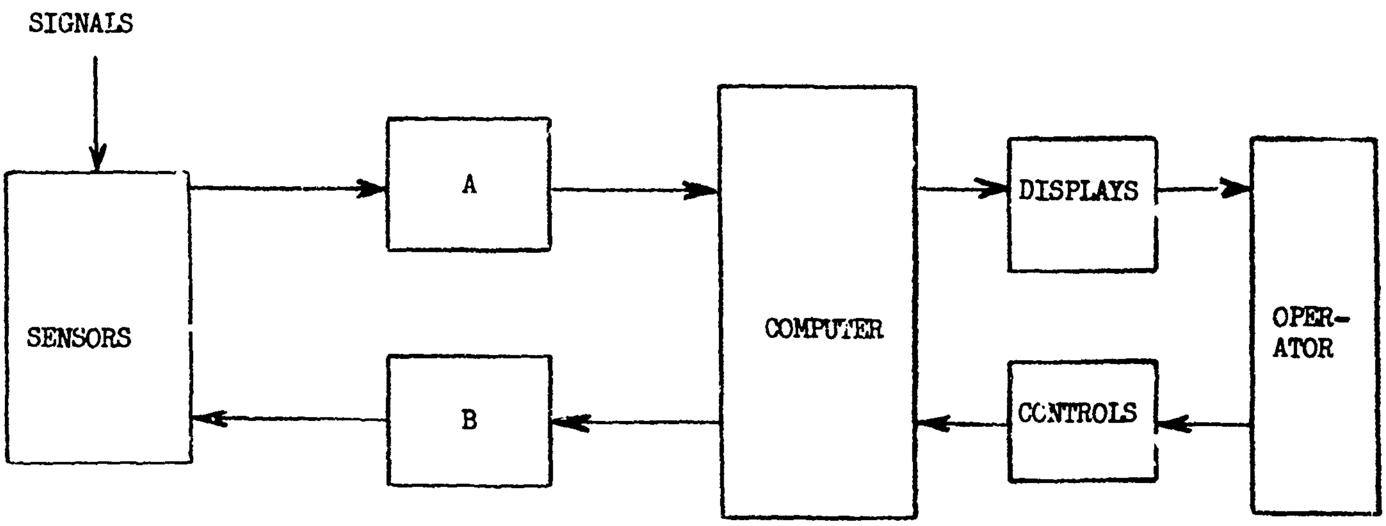

Figure 2b. More Complex Loop with Submerged Elements

Figure 2. Computer Interface Loops

RISK CRITERIA VS COMPUTER DECISION

The dangers of underestimating the prime computer's role have been emphasized in terms of its interface requirements. However, when we look in general at the risks of specifying a trainer the risks segment themselves into two classes.

1. The lowest risk class is the definition of generic trainer requirements, such as problem formulation, freeze and replay capability, trainer world size, instructor displays, exercise and trainer world content, and selection of prime system functions essential for simulation. These requirements are generally satisfiable with reasonable mutual contracting risk.

2. The second risk class represents the much higher mutual contracting risk, and is the more difficult to quantify. The simulation requirements for an operational system are generally easy to specify if one addresses only the sensor stimuli and the operator's display and interactive system controls.

What is most difficult to specify,because of its evolutionary nature, is the internal system interfaces with the computer and its software system. The definition of these interfaces is a complex and iterative task — one not even

totally completed until production delivery of the prime system (if even then). What generally occurs, at this point, in the requirements process is the specification of the prime computer system on the premise that the prime manufacturer solves his interface problem, and the trainer contractor can then merely react and modify his device. What tends to be overlooked in the specification requirements for the simulator is that for each prime computer interface there is at least one and generally two interfaces — hardware and software. The simulation and monitorship functions required to accomplish the trainer peculiar functions of problem formulation, exercise and replay require well-defined interfaces to achieve the required trainer performance fidelity. Modification of hardware interfaces becomes costly and schedule restrictive; software on the other hand tends to be readily modifiable. This continual flow of interface changes affecting established trainer baselines inevitably impact program cost and schedules, and ultimately result in tradeoff on device fidelity and configuration compatibility with the prime system. The resultant mutual contracting risk resolves itself into schedule adjustments, cost increases and specification modification, none of which totally satisfies the initial contracting intents.

If it is assumed that a decision has been made to simulate the prime computer functions, then does not the same contracting risks evolve, as with prime hardware? The answer is a resounding NO. The requirement for explicit interface data is drastically reduced, internal trainer interfaces are reduced, trainer design can be accomplished in parallel with the prime system, and prime system specifications and performance requirements become a trainer design reference. The cost and schedule effects that result from prime system interface changes are avoided. What now results is a shift of mutual contract risk, from those related to the continual prime system design changes, to those of less frequent prime system performance changes. This provides both parties the design flexibility, and most effective use of program funds to maintain trainer/prime system configuration compatibility, and to achieve planned training need dates.

In summary, figure 4 depicts the relationships of aggregate risk of specifying a trainer hardware configuration, when interface data is evolutionary. Risk is minimized by simulation of the computer subsystem during early stages of parallel development. The correlary condition is mutual risk increases whenever prime hardware is specified for trainer utilization, when the prime system is under parallel development.

A major risk area frequently overlooked is the supportability of a trainer after introduction in the training environment. Trainer availability is a direct result of its reliability and personnel ability to maintain its performance in an operational environment. Careful tradeoffs must be accomplished to ensure the added trainer complexity,resulting from imbedding prime system computational capability,does not seriously complicate troubleshooting and maintenance capability. Hidden factors that degrade true training availability, such as prime system support equipment dependency, spares priorities, modification lead-times, prime and trainer computer system maintenance priorities, are problems that must be realistically evaluated. It is obvious that many of these trainer availability limiting factors are minimized when only a single non-prime hardware computational element contributes to the true availability.

SUMMARY

The tradeoffs which culminate in the decision whether to utilize prime system computer (and software), or to simulate its functions by trainer peculiar techniques are not clear-cut. The use, time, technical and risk-related criteria must be objectively evaluated for each particular trainer application. Figure 3

depicts a logical sequence related with salient factors that influence the trade-off decision of criteria analysis. This listing can provide the basis upon which the final tradeoff decisions can be based. As more tradeoffs are conducted on future simulation device requirements, quantitative relationships should emerge, which will simplify, and add increasing creditability to the decision process.

In the actual tradeoffs, which have been conducted, the single most important element that influences the various decision criteria is time. If required training need dates are to be met the parallel development of both the prime system, and the trainer is required. This program requirement imposed in tradeoff analyses invariably results in decisions tending toward simulation of prime equipment computer functions.

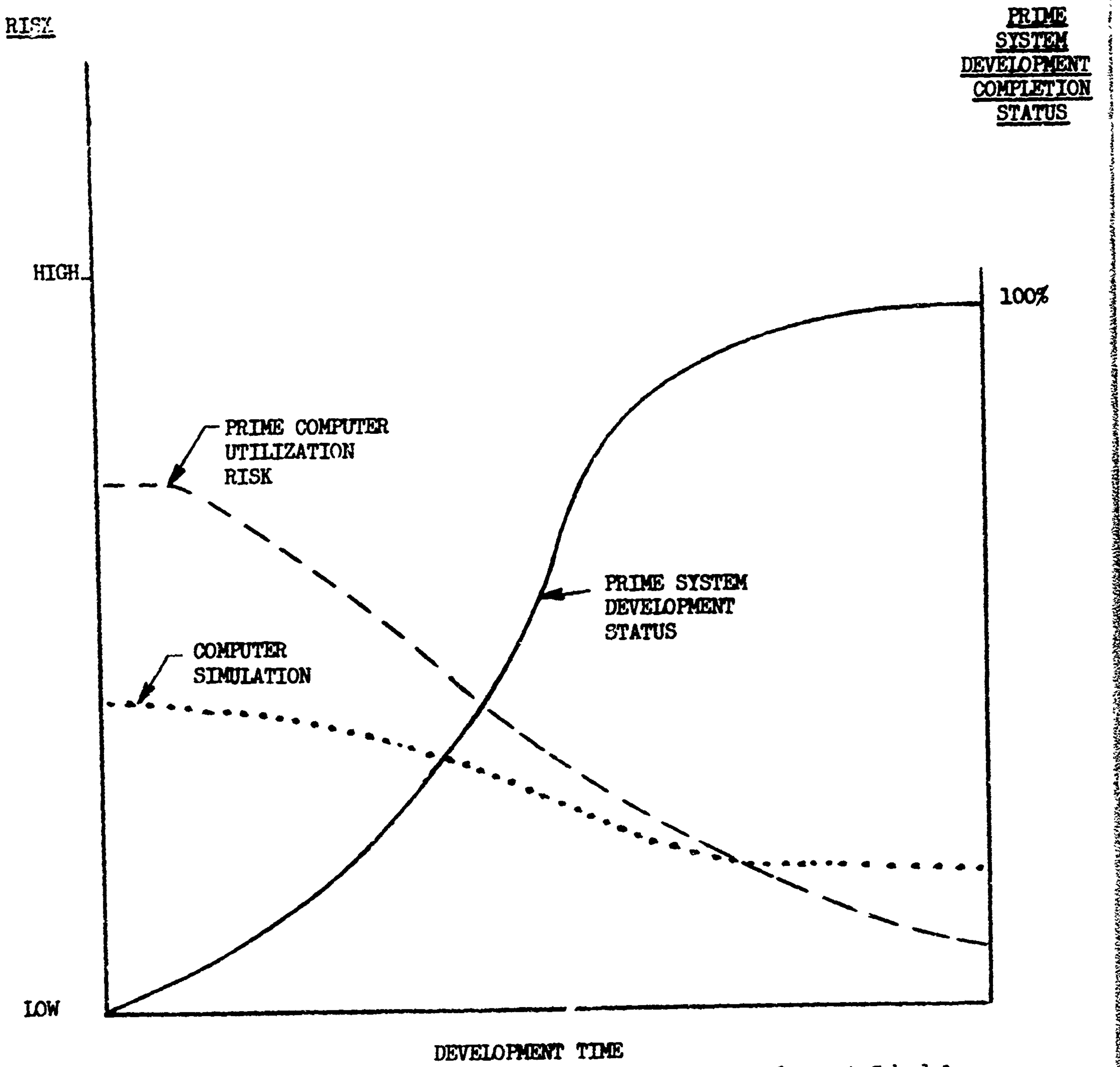

Figure 3. Composite Risk vs Prime System/Trainer Development Schedule

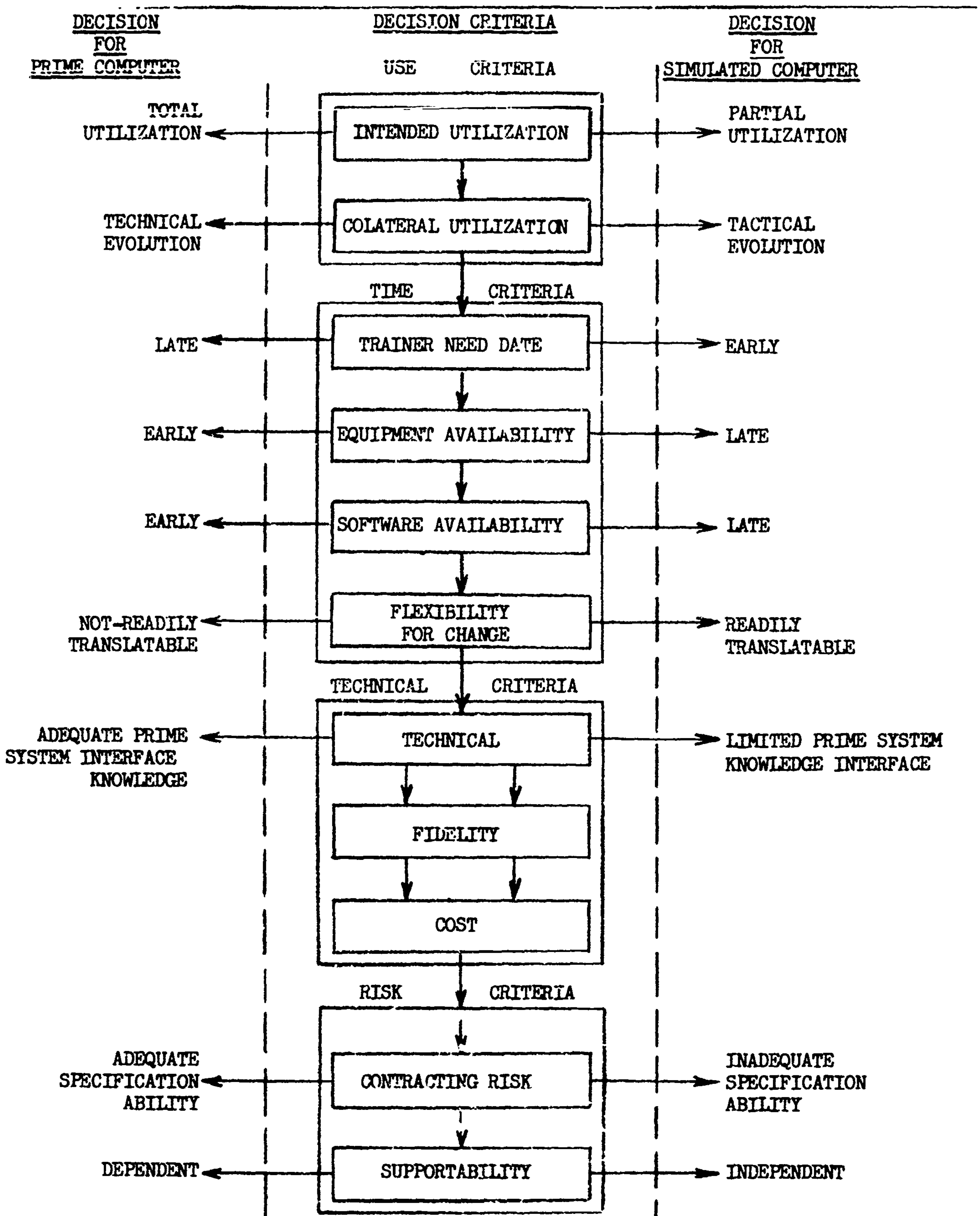

Figure 4. Criteria Analysis Relationships

INSTRUCTOR CONSOLE INSTRUMENT SIMULATION

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INTRODUCTION

The application of computer-generated displays to training device instructor consoles was until recently a relatively unexplored area. The traditional use of digital computers for control of instructor console instrumentation, such as repeater instruments, pushbuttons and indicator lamps, is well known in the training device industry. Several introductory attempts at improving speed of simulation response and extending the content of instructor communication, with the simulation computer, have utilized computer generated alphanumeric display. However, utilizations of highly interactive, computer-generated graphic displays in instructor console applications have not yet been developed.

The objective of the aircraft instrument simulation on the Naval Training Device Center's in-house display system was to verify the capability of using interactive, computer-generated graphic displays in instructor console applications. The concept was verified by satisfactorily simulating the instructor console instruments for the F4 Phantom flight simulation on the TRADEC display system. (TRADEC) is an acronym for the in-house Training Device Computer facility at the Naval Training Device Center (NAVTRADEVCEN).

The F4 flight instruments cover the full range of complexity and diversity found in modern simulator systems. In addition to the feasibility demonstration, the display programs developed for simulating the individual instruments will provide facilities to perform experiments in man-machine interface, instructor console design, display format, and instructor communications.

Availability of the TRADEC display system interfaced to the Sigma 7 computer provided an excellent opportunity to accomplish a complete simulation of the TRADEC F4 instructor console on the display system.

SYSTEM DESCRIPTION

<u>TRADEC Simulation Facility</u>. The TRADEC simulation facility consists of a Sigma 7 computer, a full complement of general-purpose peripheral equipment, a simulated F4 Phantom cockpit, mounted on a four-degree-of-freedom motion platform, an operator's control console, and a display system with a display computer and two display terminals. See figure 1 for a block diagram of this system's configuration.

<u>Display System</u>. The display system was manufactured by Information Displays, Inc., and is known as the IDIIOM (IDI Input Output Machine). It uses: (1) A Varian DATA 620/i computer as a buffer for display programs; (2) a display processing unit to execute the display program; (3) function generators; and, (4) display consoles.

1. The DATA 620/i mini-computer core memory has a 16-bit word length with a 1.8 microsecond full-cycle time. Present memory capacity is 8,192 words. This computer controls the interface with the Sigma 7 and also controls the display processor.

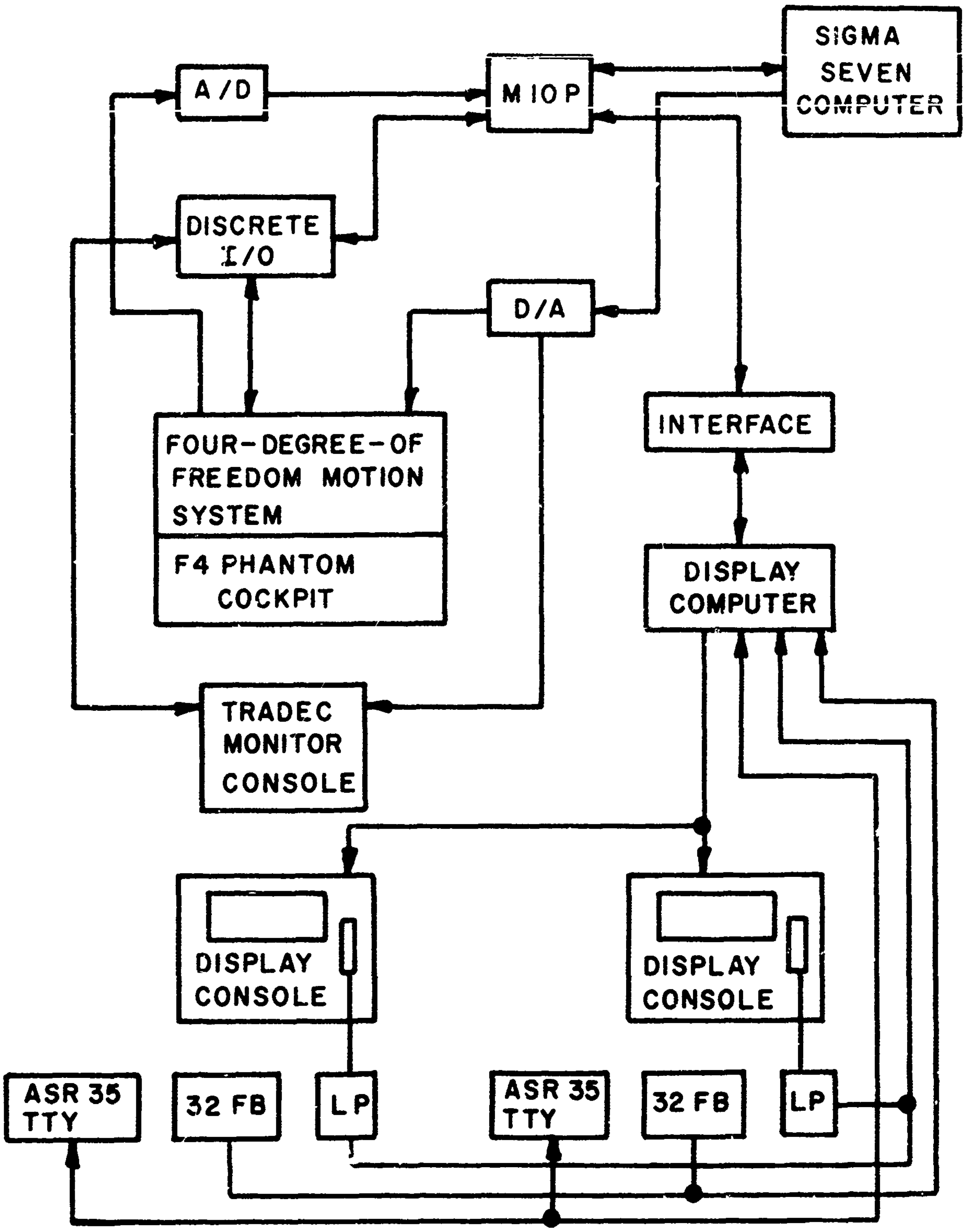

Figure 1. Block Diagram of System Configuration, NAVTRADEVCEN In-House Simulation Facility

2. The display processor repetitively executes a program of display instructions to provide continuous updating of the CRT phosphors. All communication between the DATA 620/i and the vector and character generators pass through the display processor.

3. The function generator units accept input from the display processor and supply the signals required to drive the display consoles. Included in these units are character generators, vector generator and beam positioning circuits, circle generators, intensity control circuits, and line drivers.

4. Each terminal has a 21-inch CRT with 13-inch square accurate display area. There are 1024 addressable points along each axis. The displays are presented as a sequence of blanked and intensified vectors. This type of display is called a calligraphic, or stroke drawing display. Each terminal is also provided a light-pen, 32 function buttons with programmable lamp indicators and an ASR teletype for input/output to the display computer.

<u>Interface between Sigma 7 and DATA 620/i</u>. The Sigma 7 interface communicates with the DATA 620/i through programmed I/O. Transfer rates of up to 30,000 eight-bit bytes per second are possible when block transfers are processed. Bi-directional external interrupts are provided for each computer, and data transfers may be initiated on either side of the interface.

<u>TRADEC Instructor Console</u>. The F4 monitor console enables the instructor or operator to control and observe the simulation problem. There are three panels at the monitor console:

a. The motion control panel, which provides complete control of the hydraulic power system and motion actuators.

b. A switch panel which generates and displays computer discrete inputs and outputs. The panel contains a bank of 64 backlighted pushbuttons, which service both as indicators and switches, and are used to control the simulation's progress.

c. The instrument panel, which houses a set of 19 cockpit instruments for monitoring simulation performances. For a view of the nineteen repeater type instruments, see figure 2.

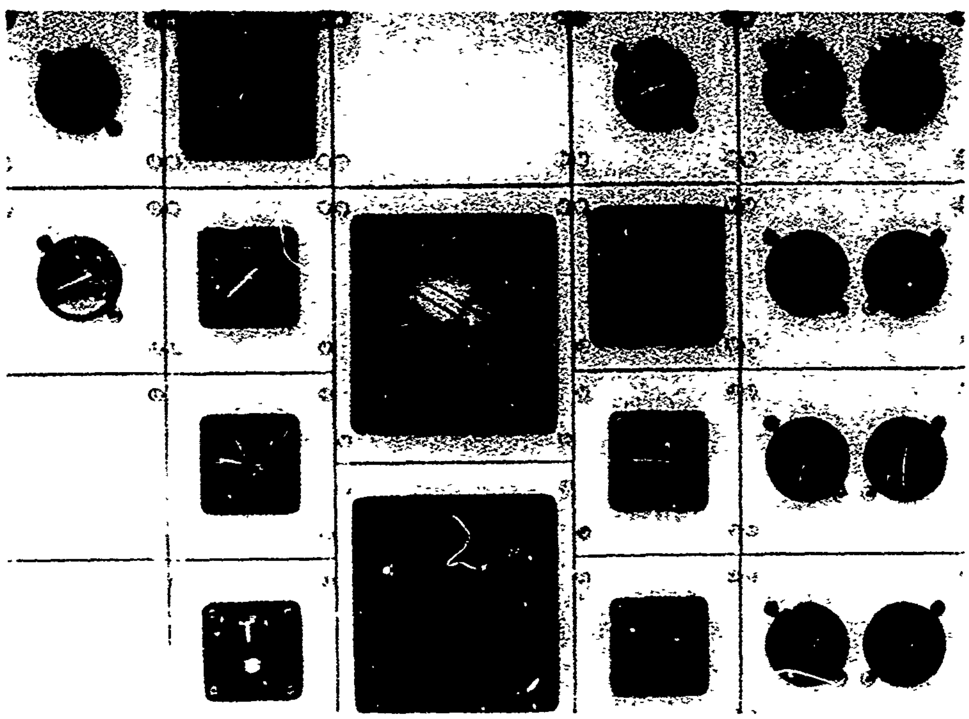

Figure 2. Instrument Panel, TRADEC Instructor Console

PROGRAMMING

Programming for the display system is more complex than single processor computer programming, since the display processor represents a second computer-like device operating out of computer memory. When the display system operates in a stand-alone mode, with no access to the Sigma 7 interface, two separate programs are simultaneously executed to provide dynamic display. With the interface connected, three programs are active at the same time. The three programs are: (1) The display program; (2) the DATA 620/i control program; and, (3) the Sigma 7 simulation and communication program.

1. Display Program. This program controls the analog vector and character generators to sequentially draw a picture on the CRT. The instructions in this program are similar to computer instructions, but result in changes to the CRT electron beam, changes in the instruction execution sequence, or changes in the internal state of the display processor.

Display instructions provide absolute and relative positioning, vector generation, point plotting, and stroke type characters. Vectors may be drawn with four levels of intensity, in one of the four vector formats: solid, dot, dash and dot-dash. Control type instructions in the display program provide display subroutining, conditional jumps, indexing, and refresh frame rate control.

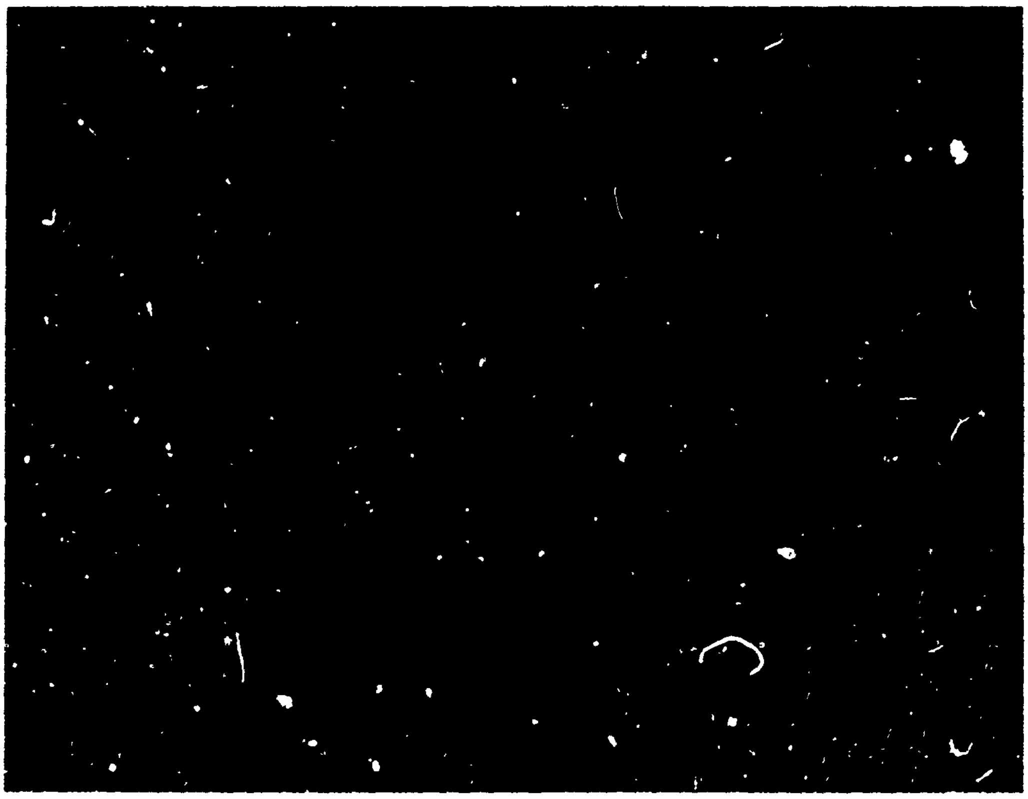

Figure 3. Computer-Generated Simulation of Instructor Console Instruments

Figure 3 shows the 19 flight instruments generated by the display program. Two thousand eight-hundred sixty 16-bit instructions were required to draw this display.

2. DATA 620/i Control Program. This program is responsible for servicing display console inputs from the programmable function buttons and light-pens. It converts instructor inputs into changes to the display program. These modifications result in the reconfiguration of the display format on the display scope. The reconfiguration is effected by:

a. Push-button selection or deletion of individual instruments on the display scope (using the function keyboard).

b. Light-pen positioning of individual instruments on the display scope.

The DATA 620/i control program contains a communications section to control the Sigma 7 to IDIIOM interface and provide real-time input of a table of F4 instrument parameters. The program is activated by interrupts from the Sigma 7, which cause suspension of the control program while inputs from the Sigma 7 are transferred. When the input transfers are completed, the control program resumes operation and modifies the display program according to the latest Sigma 7 inputs. These modifications provide the dynamics to the various instrument indicators. The communications section is activated during each fifty millisecond iteration of the F4 program cycle. The DATA 620/i control program occupies 3,415 memory locations in core memory.

3. Sigma 7 Program. An active F4 simulation program in the Sigma 7 dynamically updates the display computer memory with current values of instrument parameters. The updated parameters are required to produce the appropriate motion of the instrument dials and indicators. To enable this transmission, the standard F4 simulation was modified as follows:

a. A new program module for constructing a properly formatted output buffer was added to the F4 program.

b. A routine to extract Euler angles from direction cosines was added to the F4 program.

c. Various standard F4 program modules, including the real-time input-output, the system parameter, and the aircraft instrument program modules, were modified.

RESULTS

All nineteen repeater instruments were simulated on the display console in as near identical format as possible using the display. The instruments were interfaced with the F4 flight simulation program, with good visual correspondence between the instructor console flight instruments and the corresponding CRT displays of those instruments.

Figures 2 and 3 demonstrate the visual correlation between the display simulation and the instructor console. The two photographs were obtained with the flight simulator in the freeze mode; i.e., the flight program was halted during a flight maneuver, and held "frozen" with all parameters fixed. This allowed a static comparison between corresponding instruments. Good correlations can be seen.

A good dynamic correspondence was observed also during simulated flight maneuvers. The various instrument component motions (such as those of the rotating, counter-type decimal indicators, the pointers, etc.) were simulated in real-time.

The function keyboard permitted the operator to select for viewing those instruments he wished to observe. Any, or all instruments could be selected for viewing. The operator could also delete any or all instruments from the screen using the function key-board.

The operator was allowed to re-position the instruments on the display scope at will. The program remembered the latest position of each instrument after its move with the light-pen. The most recent position coordinates were recalled from memory following a "delete" operation followed by a subsequent "restore" operation.

The function keyboard provided an additional operator-control feature: The choice of either synchronous or asynchronous display refresh rate. Depressing the function key labeled "S" lock-synchronized the frame repetition rate to the power line frequency, or a sub-multiple thereof; while depressing the key labeled "A" allowed the frame rate to be a function of the display program length. To display a large number of instruments, it was advantageous to select an asynchronous refresh rate to decrease the flicker effect. On the other hand, to display only a few instruments, the synchronous refresh rate was preferred to prevent excessive brightness on the scope.

CONCLUSIONS

The primary task in meeting the objectives of this study was to duplicate the functions of the present TRADEC F4 instructor console on the in-house computer-generated display system. The instruments have been successfully simulated and interfaced to the F4 program. The control functions represented by sixty-four backlighted pushbuttons on the conventional instructor's console still remain to be simulated. These will probably be represented by a light-pen selectable menu of options around the periphery of the display screen.

The second objective of this study was to develop a control program to allow interactive control of display formats. This has been done in the present version of the control program. The program can easily be modified, and changes, or additions, will be made to incorporate improvements throughout the remainder of the project.

Even in its incomplete form, the present version of the instrument simulation program has demonstrated several potential future applications. The instrument simulation has already been used by simulation technicians in verification and alignment of both on-board simulator instruments and instructor console repeater instruments. The displayed indication is derived directly by simulation parameters within the TRADEC Sigma 7 program and provides direct access to the parameters without distribution to the analog instrument outputs. For this reason, the display simulation provides a useful backup and check on the indications of the actual instruments.

The ease of display control will provide research capability for human factors use in instructor task definition. The flexibility in reconfiguration of display formats on the simulated console provides a useful tool for human factors studies in defining the instructor tasks in controlling and evaluating trainee performance. An instructor can reposition instruments on the display to provide close monitoring of groups of instruments. Such grouping is not available on a conventional console, and regrouping would require considerable labor in physically repositioning instruments on the instrument panel.

Completion of the simulation of the F4 instructor console instruments and controls on the in-house display will represent one of the first successful applications of interactive computer-generated displays in a real-time aircraft training device simulator. The simulation will provide excellent flexibility and improved performance in instructor monitoring and control functions at slight increase in cost in the loading of the aircraft simulation program. The interface communication between the simulation computer and the display system is also very light. Transmission of the updated table of simulator parameters must be accomplished each simulator program cycle, but this is only 34 sixteen-bit words each fifty milliseconds, or a total of 680 words per second. This is extremely light considering that a transfer rate of 15,000 words per second is achievable through the interface.

Incorporation of similar consoles in future training devices will provide standardization in hardware, while increasing performance. Hardware standardizations will result in savings in maintenance, provisioning, and training for maintenance and operator personnel.

STATUS OF COMPUTER-GENERATED IMAGERY FOR VISUAL SIMULATION

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The basic task of visual simulation for training is the provision of out-the-window scenes for the pilot which respond realistically to his control movements. Many requirements are placed on the visual scene so produced, the most important being that the scene respond in real time and that it provide the appropriate visual scene to the pilot to make him think that he is actually traveling through the simulated environment.

Computer Generated Imagery (CGI) technology approaches the task of providing suitable out-the-window scenes by using special purpose digital computing hardware to scan a mathematical environment model. The scene so produced is presented on a television output device, with the picture being updated thirty times per second.

CGI systems possess certain significant capabilities not easily attainable with other visual simulation techniques. Among these are the ability to move in the environment with full six degrees of freedom, availability of an extensive operating area within the environment, and freedom from optical or mechanical system limitations. Because the environment is really a mathematical description in computer memory, there is no limitation on where the pilot can go or on what attitude he can get into. Since the mathematical scanning process used to present the scenes on the display device is performed with a theoretically infinitely-small aperture, there are no depth-of-field problems. The image is in focus throughout the scene.

Since several adjacent views of the environment can be computed from the same eye point, it is possible to juxtapose field-of-view segments to provide a viewing window of almost any desired angular extent. The problems of sensing the image, however, are greatly simplified by the freedom from limitation on look-direction inherent in CGI systems. The principles upon which a CGI system operates are illustrated in figure 1.

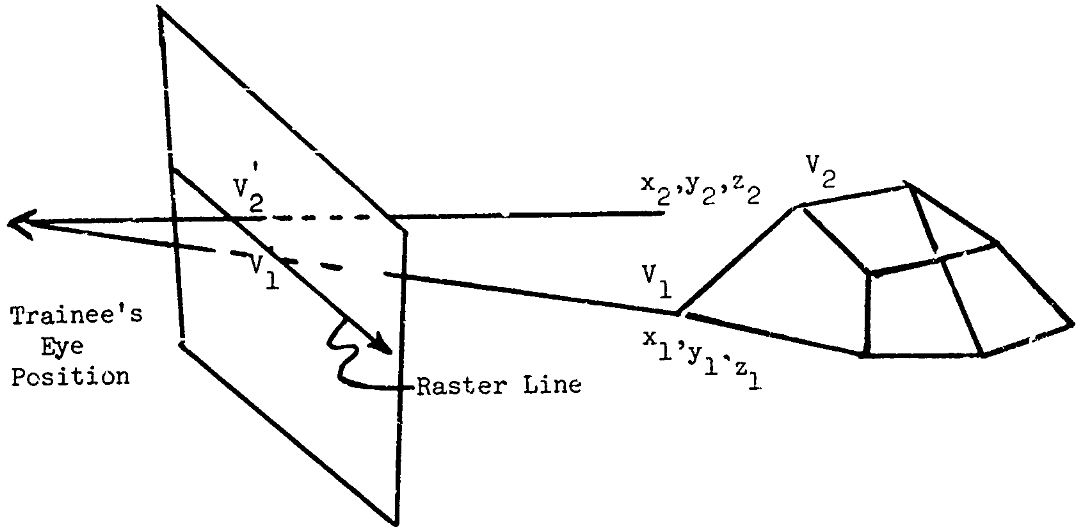

Figure 1. Principles of CGI System Operation

Each object in the mathematical environment is described by the x, y, and z coordinates of its corners, or vertices, in a fixed ground coordinate system. These coordinates can also be thought of as vectors from the origin of ground coordinates to the various vertices. The position of the trainee's eye point and the display plane, which corresponds to the screen of the display device, are tracked in real time by means of a dynamic vector which describes their position relative to the ground coordinate system. At the beginning of each television frame, the vectors from the eye point to all the environment vertices are found by adding in the eye point vector to each ground coordinate vertex vector. This set of vectors forms a valid description of the entire mathematical environment as seen from the trainee's point of view for the present television frame.

Given the set of vectors describing the scene, the CGI system first performs a perspective transformation from the three-dimensional mathematical environment into the two-dimensional display plane. This transformation is performed on each edge in the environment. (An edge is a straight line segment joining two vertices). The task remaining is to perform a scanning operation of the transformed edges in the display plane in synchronism with the television raster. At each instant in time, the system must determine which face of an environment object is visible through the point being drawn on the display plane at that instant. The color of the appropriate face is the color that should be presented on that raster element.

Several CGI systems are in operation at the present time. The first system capable of producing real-time scenes of three dimensional objects was installed at the NASA Manned Spacecraft Center in 1967. This system is capable of accommodating environments involving up to 240 edges and can drive up to three independent, full color views of the environment simultaneously. The 240 edge capacity is divided between the independent views when more than one view is used. Additional equipment will be delivered to NASA in 1971 to expand the capacity of this system to 500 edges.

Several organizations are presently using computer-generated image techniques for producing complex and realistic pictures in a slow time mode. A storage medium is used to accumulate the computed elements of the picture until an entire picture has been prepared, and the picture is then displayed. The basic principal is that of trading computing time for image complexity, sacrificing the ability to operate in real time. Many of the groups using these techniques are aiming their developments primarily at film making and computer graphic applications, without any intention of eventually producing real time simulation systems. Other organizations, however, use their slow-time systems as essentially non-real-time CGI systems for use in development of real time capabilities. Three such machines are installed at various General Electric Company locations, and Evans and Sutherland Computer Corporation at Salt Lake City, Utah, has been producing perspective scenes of very high quality and complexity for several years. The Evans and Sutherland work is performed in cooperation with the University of Utah.

These non-real-time CGI systems are not useful for simulation purposes since they cannot produce updated pictures fast enough to give the impression of motion through the environment. However, they provide a valuable means for evaluating advanced hardware concepts and for making movies by single frame techniques to allow assessment of subjective effects. They allow making CGI pictures with a small investment in hardware, and they allow their users to evaluate system concepts and algorithms without facing the many high-speed logic problems involved in implementing a real-time system.

A real-time CGI system is in operation at General Electric's Apollo and Ground Systems facility in Daytona Beach, Florida. This system has a capacity of 256 edges at the present time, and can drive one field of view. Effort is now underway to expand capacity to 500 edges and two view segments by the Fall of 1971.

Another CGI system is also now under construction at General Electric's Daytona Beach facility. This system will have a real time capacity of 500 edges, but it will be able to operate in an environment involving up to 2000 edges, with selection of the appropriate 500 edges for display being made on a real-time basis. This system will utilize three juxtaposed viewing channels, giving a field of view of approximately 180° horizontally by 60° vertically.

Since the introduction of the first CGI visual systems, certain limitations have conflicted with the application of CGI in a wide variety of training systems. Most of these limitations can be classified into two categories; image realism and cost.

Since the computing capacity required is a function of the number of edges in the environment, systems have traditionally had the capability of handling fewer edges than were really needed for satisfactorily real-looking scenes. Furthermore, the changing of displayed colors in synchronism with the main system clock leads to a quantization of data in the direction parallel to the raster lines. This leads to a stair-step effect which interfered with picture realism. Also, since the computations are performed for all objects, even if their display plane projection is smaller than a resolution element, scintillation and blinking on and off of distant small detail in the scene produces annoying results.

Developments in recent years have produced a significant progress in both picture quality and in system cost.

Systems having the capacity for handling 500 to 1000 edges can be produced with relative ease at present, and the capability for operating within an environment data base considerably exceeding the real-time edge capacity of the system has also been developed. This last capability has been pursued by many developers for considerable time, but developing efficient criteria for selecting the appropriate environment elements for display has made this goal difficult to achieve. Today, however, a hardware/software system has been developed which selects the correct environment elements in real time and uses a minimum of computational capacity.

Another recent development which complements the environment data base techniques described above is the capability for selecting one of several increasingly complex versions of each object to be displayed in the environment, in order to use only that edge capacity on each object which is required to present it to the level of detail that can be perceived.

Hardware has also been developed for providing limited visibility and weather effects. The illustration below (figure 2) shows the basic model used for producing weather effects. A layer of visibility-reducing medium is specified by the height of its bottom (h_b), the height of its top (h_t), and a quantity specifying the density of the medium (d). For each point in the displayed image, the range R through the medium is computed. The contrast ratio of the environment element seen through that point--in the case shown, the ground surface--is reduced as a function of the value of R. For the situation illustrated, the simulation would be of a situation having a layer of fog. The eye point could start above the layer, break into the layer, and then break out at the bottom.

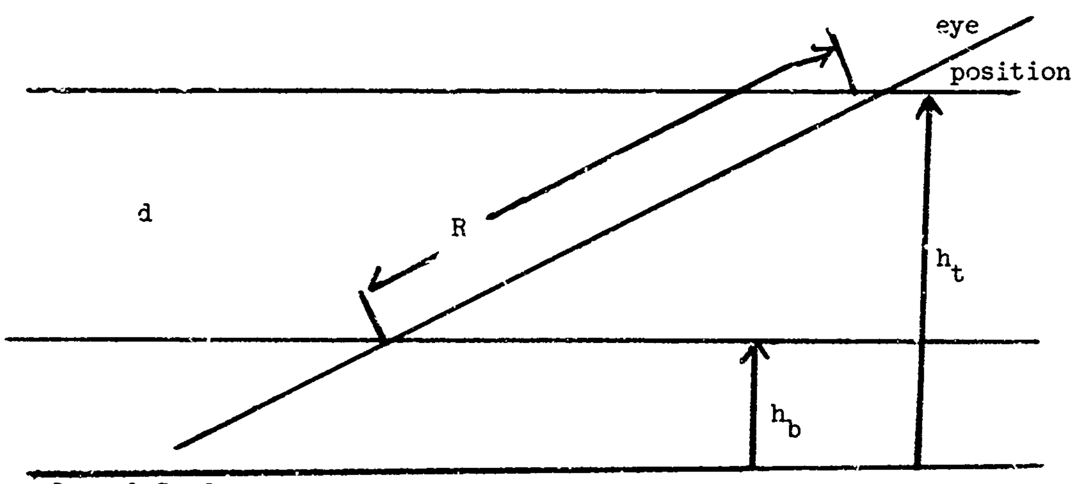

Figure 2. Basic Model for Producing Weather Effects

If the density (d) is made a function of altitude, effects of forming or dissipating fog can be simulated. If (d) also varies with North-South and East-West position, a simulation of clouds can be achieved.

Figure 3 shows a view of a runway with a simulated visibility range of 2,000 feet.

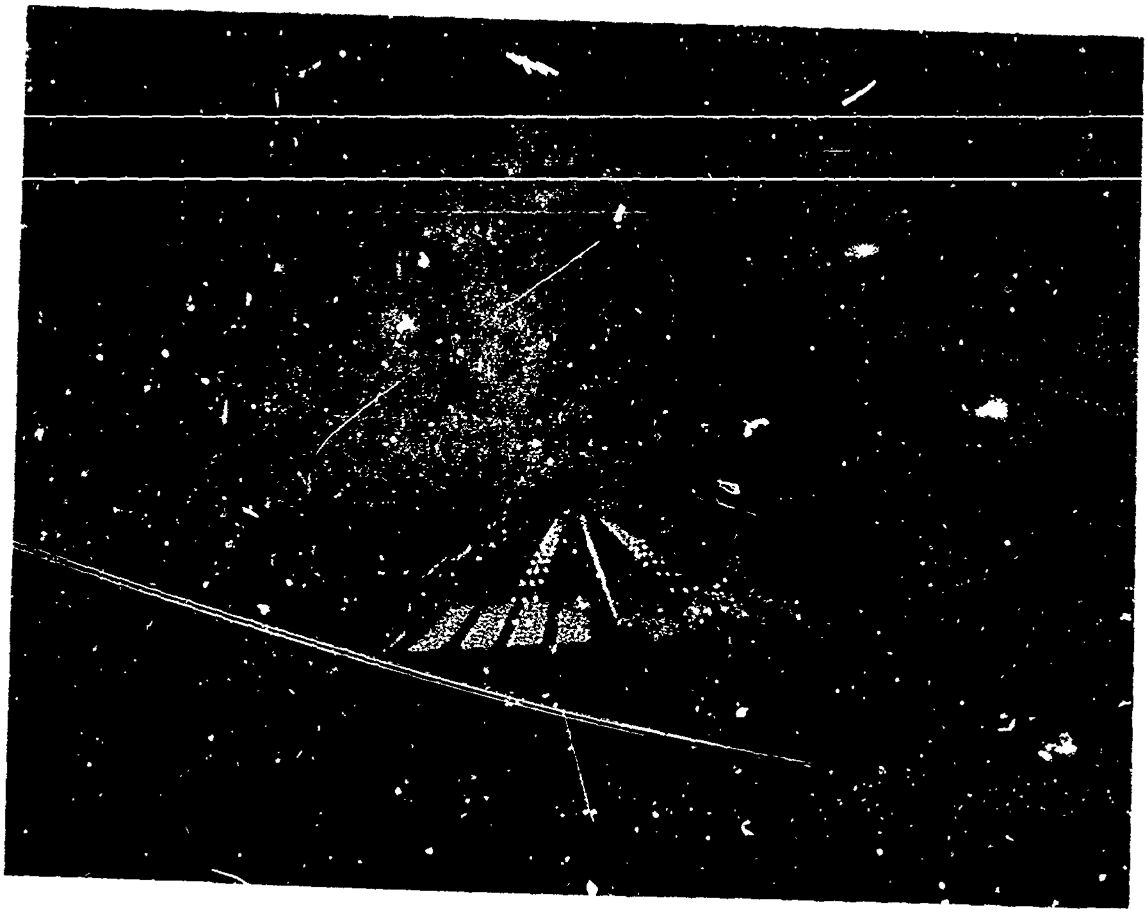

Figure 3. View of Simulated Runway NOT REPRODUCIBLE

Another developed capability allows presentation of large number of lights, such as runway lights, with greatly reduced hardware complexity. Special features of lights, including effects of visibility-reducing media, effect of range on brightness, and directionality are also treated.

In order to take advantage of the inherent multiple view capability of CGI, a method has been developed for assigning environment objects to the view segments in which they appear, so that computations do not have to be duplicated for each segment in which the object might appear. In the system delivered to NASA in 1967, it is necessary to divide total edge capacity between the viewing segments. In the larger system under construction at General Electric in Daytona Beach, any of the edges can appear in any of the three view segments without deterioration of edge capacity. In addition, the view channel assignment hardware removes all edges which fall completely outside the field of view, with an attendant improvement in edge capacity. From the standpoint of improvements in cost, it is interesting to note that this system, despite its 2000 edge capability, costs considerably less than the 1967 NASA system.

Although many advances have been made in recent years, much advantage can be gained from developments now in process. One of these areas of effort is in increased resolution. Previous CGI systems have varied little from 525-line television standards. Picture resolution up to 1000 lines has been achieved on some of the non-real-time systems, but the

problems of exceptionally high computational rates do not have to be faced with these systems. Lack of availability of color cathode ray tubes capable of presenting 1000 line pictures has also been a problem. Solution of the computation and display problems should occur in the not-too-distant future and will contribute greatly to picture realism.

Another current development area relates to the elimination of adverse effects that result from the raster quantization--commonly referred to as the stair-step effect. The basic problem is related to the fact that the CGI system generates the picture in discrete blocks, each having a height of one raster line and a width equal to the distance traveled by the electron beam in one basic clock cycle. This differs from the process that occurs in a television camera, where the allowable variation in brightness color along a raster line is essentially continuous and limited only by the system video bandwidth. A technique is under development now which essentially puts some of the analog characteristics of a camera system into the digitally computed video, and it shows considerable promise for reducing the stairstep problem.

Although considerable progress has been made in the system cost area, there is still much room for improvement to allow meeting the requirements of low cost simulation applications such as driver training. CGI visuals, if developed for sufficiently low cost, can provide interactive training for vehicle operators for testing and skill development. Currently, this type of visual for driving training is not available in any technology. Improvements in system architecture and product-oriented design show promise from bringing CGI visuals into the price category permitting their use for these applications within a few years.

COMPUTER-ASSISTED INSTRUCTION
(THE SFTS AS A COMPUTER-CONTROLLED TRAINING DEVICE)

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INTRODUCTION

I would like to open by giving credit to John Walsh who is now working for the General Counsel's Office of the FAA. John was primarily responsible for the conceptual development and implementation of Automated Training in the Link Synthetic Flight Training System, (SFTS).

THE SFTS AS A COMPUTER-CONTROLLED SYSTEM FOR TRAINING

Many training devices utilize computer driven equipment to provide training in tasks related to the operation of aircraft, locomotives, spacecraft or weapon systems in a total system called a simulator.

The SFTS is more than a simulator. It is a total training system which utilizes four UH-IH helicopter simulators as a part of the training system. The other parts of the system use feedback response from each of the four simulators to determine what the system should indicate to the instructor, the simulator, and the student(s).

The basic components of the system are:

- Four UH-IH cockpit simulators on motion bases
- Instructor's station controls
- Displays
- Aircraft sounds, taped messages for student exercises
- Computer complex for display system
- Computer complex for aircraft related systems and automated training.

Major functions of the total system are:

- To simulate UH-IH aircraft
- To respond to and control inputs to an instructor's station and student station
- To record information
- To control audio tape messages presenting training situations to the student
- To display student performance information
- To analyze and score student performance

This system faithfully simulates the UH-IH helicopter in terms of its associated systems, which include such things as airframe, power plant controls and indicators, and avionics equipment.

A complete instructor's station is capable of managing training in four cockpits simultaneously and of providing instructor/student communication, data displays (CRT's for student and instructor), data control, problem monitoring, training problem selection, malfunction control, closed circuit television control, flight recording control, and hardcopy device output control.

In addition to the capabilities mentioned, the device is capable of performing in two modes of operation, using different cockpits simultaneously. These modes are manual and automatic.

The manual mode need not be discussed because the automatic mode of operation is a derivation of the manual capability.

In a system that is completely controlled by a computer complex, the term AUTOMATED MODE of training, is an indication that the system is controlled by a computer and provides computer assisted instruction (CAI). This should become clear as we progress in the presentation.

COMPUTER-ASSISTED INSTRUCTION

Primarily, the function of the computer in a system such as this is to completely control all aspects of system operation. Since this is inherent to the system it implies the most important aspect of the system, that is, the <u>COMPUTER is always aware of what is happening.</u>

Since the computer recognizes student inputs it will react, during like training situations the same way time after time, regardless of who the student is. The computer never has a hangover from a night out.

In other words, the computer is in the system to assist instruction, because it is free from natural human weaknesses, it can anticipate actions, it will always respond in the same manner for every student for every training situation programmed into it. Actual flight situations can be duplicated and student execution monitored for comparison to established performance standards.

This brings up another important fact about COMPUTER-ASSISTED INSTRUCTION. The computer is a flexible instructor. It can be given new criteria to use, when scoring students, it can be given new methods to use in controlling the system, and it can be given partially or totally new training assignments without the need for a new device. This is accomplished by modifying existing computer programs and data (software), or developing additional software.

AUTOMATED INSTRUCTION IN THE SFTS

FUNCTIONS OF THE INSTRUCTOR'S STATION AND ASSOCIATED EQUIPMENT.

There are four functions which the computer performs for the SFTS while it is controlling the four cockpit simulators during automated training. These are:

1. Monitors and controls instructor station and associated equipment
2. Controls cockpit pilot training aids
3. Initiates information storage and retrieval
4. Selects and executes programs

The computer monitors the mode control switches, providing inputs to student monitoring devices at the instructor station such as: displays, selected student aircraft instruments, displays for ground tracing, altitude and vertical velocity plotting. Provisions exist for cueing and selecting appropriate devices for communications. In addition, the computer provides hardcopy printout, when the instructor requests it, for all cockpits. If the instructor wants to insert a training period or portion of a period for a student in a particular cockpit, he interrupts the actions for a selected cockpit. Through the use of a thumbwheel switch and pushbutton switches he can override anything that the computer is currently doing.

Malfunctions are programmed into selected problems. The instructor can prevent these from being automatically inserted by watching for displayed indications that it will be inserted and then inhibiting or removing the failure for the cockpit.

The instructor interacts with the system in the automated mode of operation. So does the student.

COCKPIT PILOT TRAINING AIDS.

The student has his normal cockpit instruments and controls. He can monitor his progress and the status of his trainer during certain phases of training by monitoring special student scoring and status indicator lamps. He can also monitor his own display unit to select training exercises, observe the map of his training area, and obtain information regarding his performance. Of course, the student can communicate with the instructor at his own discretion.

AUTOMATED TRAINING DESCRIPTION

All of these functions are going on during an automated training session. An automated training period is made up of the following:

- Briefing
- Demonstration
- Guided Practice
- Adaptive Practice
- Related Problem

A BRIEFING is automatically selected by the computer by cueing a particular selection on a tape to play through an audio system. The briefing will tell the student what to expect during the training period and tell him to start when he is ready.

During a DEMONSTRATION the cockpit is totally driven by the computer to do what the briefing has described.

When a GUIDED PRACTICE is in progress the student is permitted by the computer to operate selected control functions.

During an ADAPTIVE PRACTICE phase the student is permitted to control selected functions, but the computer inserts a selected parameter variation to increase level of difficulty in response to the student's performance. The adaptive variable is modified to make a task easier if the student has an error rate that is too great for the task being performed, or to make a task more difficult by increasing the effect of the variable if the student has a low error rate. When the computer acknowledges that the student has reached the end of an assigned task without reaching the maximum difficulty level as the result of his error rate being higher than that which is acceptable, the computer will automatically recycle the student through the task for more practice. If, however, the student reaches the minimum difficulty level when the computer is specifying further decreases in level of difficulty and the error rate is still too high, the computer will automatically stop all action so the instructor can intervene for consultation with the student. When the student has progressed to the highest level of difficulty for a task with acceptable error rates, the computer will proceed to "setup" for the next task. When a student is executing a problem during training he has complete control of the cockpit, but the computer is monitoring and scoring him throughout the problem, providing data to the system to be saved for instructor reference for critique and/or evaluation.

AUTOMATED TRAINING DATA

From the preceding statements it can be concluded that large quantities of data are being supplied to the computer to control the training program, sequencing of events and also for recording performance. The SFTS utilizes disc storage for this capability.

Automated training data is retained on the disc for use by the computer for training control. The computer also collects and organizes specific student performance data for output and later statistical analysis and review. This is accomplished simultaneously for each cockpit.

HOW THE COMPUTER ASSISTS INSTRUCTION

CONTROL FUNCTIONS.

The computer has stored in an internal memory complete sets of programs which provide:

- For monitoring and controlling all switches and lamps in the system
- For initialization of each cockpit to any one of nine training periods selectable by an instructor or student

- For information storage and retrieval
- For dispersing data to appropriate systems
- For selecting which programs should be executed and what the sequence is and when to execute.

The computer programs are controlled by a program called an EXECUTIVE. The function of the executive program is to control the WHEN and WHAT of a system of programs. When a cockpit is to be initialized, a particular program produces outputs, which set the device up, in a predetermined condition based on selected data retrieved from a particular disc file record. When this process is complete, the programs executed are those necessary for automated training. These are:

- Flight control
- Student performance measuring
- Automated demonstration
- Automated guided practice
- Automated adaptive practice
- Alert message control
- Displays control
- Automated malfunction selection
- Problem control
- Performance recording

and many more.

TRAINING FEATURES.

The features of the system, which are a result of the execution of these programs, are completely computer-controlled training periods

- Briefings, demonstration, guided practices, adaptive practice and problems
- Performance monitoring and recording
- Copilot relief
- Debriefing tapes
- Auto malfunctions and communication scripts for instructors

SUMMARY

PRESENT SYSTEM.

In brief, the SFTS system is a completely computer-controlled four cockpit training device. The instructor's role is one of interaction in the system only as an integral part of the system.

The computer has programs which are controlling a dynamic feedback response network. While the Computer programs are causing reactions to the outputs of each independent simulator, other programs are:

- Monitoring student and instructor setup requests
- Obtaining information from the disc file
- Putting data on the disc

- Monitoring student performance
- Selecting programs to be executed by the computer
- Controlling the display of information to both student and instructor
- Controlling the aural information presented to the student

It is important to remember that the computer has been programmed by humans. One must realize that the computer is merely an extension of the human brain, but it cannot learn. Its primary attributes are repeatability and programmability.

It is possible for the student to beat the system, that is, achieve a high score without performing in a prescribed manner. This is why the system has measures that are a reflection of performance criteria and do not simply correlate with them. Therefore, the computer truly assists the instructor by eliminating human subjective evaluations, when objective measures can be applied to each student, based on a prescribed set of training situations which each student must perform.

FUTURE COMPUTER ASSISTED INSTRUCTION.

The current Synthetic Flight Training System lends itself easily to future applications. In its present form, new and varied training exercises can be added to its automated training period repertoire by making adjustments and/or additions to input data. Also, as pilot requirements change or evaluation criteria change they can be readily incorporated into the existing system (programming) without the need of an entirely new device.

Automated training need not be restricted to aircraft alone, but can be used for nuclear and non-nuclear power plant operator training, ASW equipment operator training, or GCA flight controller training, just to name a very few.

Automated training techniques can be applied in any training situation that requires objective performance measurement, flexibility of criteria for evaluation, and the capability to apply new techniques to an existing device, or to a new device.

SAFETY ASPECTS IN AVIATION PHYSIOLOGICAL TRAINING DEVICES

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INTRODUCTION

This topic has been selected for discussion because of the rather unique problems associated with safety, when dealing with a group of devices, which we commonly refer to as Physiological Trainers. Safety, of course, is a subject that is written, shown, talked, and even preached about by virtually every segment of our society. However, in these trainers safety becomes the primary design criteria with all required hardware acting to support this one goal.

In this paper, it is intended to discuss this "safety as a design goal" by first briefly discussing Physiological Trainers and their training objectives, and then give a summary of a few of the more "notorious accidents" which bear directly on engineering design as applied or, in these instances, misapplied to physiological training environments.

PHYSIOLOGICAL TRAINERS AND THEIR TRAINING OBJECTIVES

Physiology, as defined in Webster's dictionary, is a branch of biology dealing with the processes, activities, and phenomena incidental to and characteristic of life or of living organisms. A physiological training device is, therefore, best described as a device associated with or causing the disorganization of physiological functions of a student. Aviation Physiological Training strives to teach the individual aviation-oriented student the "art," for lack of a better word, of survival when placed in an environment which is abnormal and potentially hazardous to him. In order to accomplish this a necessary part of the training must, in fact, cause a disorganization of physiological functions of the student. This is accomplished under controlled conditions, but unfortunately in some devices, in potentially hazardous personnel environments.

Typical of these devices are the Device 9U44 series, Dilbert Dunkers; Device 6EQ2 series, Ejection Seat Trainers; and probably the most complex and hazardous physiological device, the 9A/9U49 series, Low Pressure Chambers.

The training objective of the first of these devices, the Dilbert Dunker Ditching Trainer, is to train and expose a student to the methods and procedures required to escape from an aircraft which has somehow managed to become "waterborne" vice "air-borne"; that is, he has gotten his wings wet because he was over water and his propeller did not want to rotate any longer, or he got a "cold-cat" shot from the deck of a carrier in the case of a jet or propeller aircraft. In order to expose the student to this situation, we place him in a carriage at a height of approximately 25 feet mounted to rails which angle at approximately 40° to a water surface. The student is fully strapped into an operational aircraft seat after which the carriage, with student attached, is released. The ensuing events can best be described as the world's wildest roller coaster ride in that the carriage impacts the water at a considerable speed and almost immediately inverts and sinks to a depth which totally submerges the trainee. The trainee, at this point, finds himself upside down, firmly strapped and held by a number of belts and fittings to a seat, and submerged under water in a disoriented condition. His proper procedure is then to coolly

and calmly release himself from the seat's restraining harness and swim out. Should he panic, and have to be extricated by safety divers, he has it all to look forward to again.

The second of these devices, the Ejection Seat Trainer, has the objective of training person l to escape from an aircraft which, in its simplest sense, is anticipated to stop flying in the very immediate future. With the advent of relatively fast maneuverable and high altitude aircraft, which includes most post-World War II military aircraft, it is virtually impossible to open a canopy, climb out a cockpit and jump, thereafter opening a parachute. As a result, the ejection seat was invented and over the years considerably improved. The various ejection seat trainers we use are fitted with different operational ejection seats at various military stations, in such a manner, as to permit a Naval aviator to undergo ejection seat training on a seat identical to that used in the particular type aircraft he is flying. In order to accomplish this training the student is placed in an ejection seat, which is at rest, in a semi-enclosed area dimensionally similar to an aircraft cockpit. The seat is attached to a sled, which is mounted to rails, and is affixed at an angle of approximately 75° to the horizontal. The student is given the proper ejection sequence and body position and, thereafter, is told to fire the seat using the appropriate activation method. Upon student activation, a pyrotechnic charge is fired causing the sled, with seat and student affixed, to very rapidly travel up the rails to a height of approximately 10 to 12 feet.

The third of these devices, the High Altitude Low Pressure Chamber, has the objective of teaching the student or, in this instance, a group of students the use of high altitude life support equipment. This includes all the various types of personal oxygen supply masks and protective helmets as well as aircraft oxygen supply regulators as appropriate to the particular aircraft to be flown by the trainee. To the extent possible, the student uses his own personal issue survival equipment in the chamber, which serves the dual purpose of training the aviator, and gives him the assurance that the equipment will actually work, should he need it in his aircraft. Along with the operation of equipment, the trainee is extensively briefed on the physiological effects of high altitude or low atmospheric pressure on his body. Demonstrations are conducted to demonstrate hypoxia, which is a lack of oxygen to the bran and pressure breathing requiring the trainee to work to exhale, and a number of other rather insidious things, which a pilot may expect to be confronted with, when flying at altitudes above 10,000 feet without cabin pressurization. The device, in which this training occurs, is a rather substantially large compartmentalized steel rectangular box,which is attached by piping to a rather substantial vacuum pump. Through the use of controlling mechanisms, the pump is allowed to evacuate a compartment or compartments of the chamber which thereby places the student in a reduced atmospheric pressure environment identical to that experienced at high altitude.

In addition to the group training accomplished in all of the 9A/9U seri Low Pressure Chambers, certain of these devices; specifically, 9A9s and 9U49B, have the capability of rapid or explosive decompression, which is used in conjunction with full pressure suit work. The full pressure suit is a rather complex garment which has the purpose of fully enclosing the human body and insuring that an atmospheric pressure is maintained on the body which sustains life (3.5 psia). This type suit has probably been seen by almost everyone in the world in that it was shown very impressively by Mr. Neil Armstrong on July 20, 1969, when he stepped on the surface of the moon. While Mr. Armstrong's suit was definitely of the very latest design it, in fact, served the same purpose as a military-type full pressure suit. In fact, if the life support back pack were removed from the NASA suit and the color was changed from white to our rather

notorious olive drab, it would be difficult to distinguish an astronaut from an F-4 Phantom pilot, flying at 60,000 feet. Since all Naval aviators are required to wear this type suit, when operating at altitudes above 50,000 feet MSL, they must also be trained in the application, operation and mobility limiting factors resulting from its use.

The Decompression Chamber variety of Low Pressure Chambers is used for this type training. In this chamber there are three locks or compartments. The main compartment is approximately 18 feet long by 8 feet wide and 8 feet high. In a full pressure suit run this compartment is evacuated to a pressure equivalent to that at 100,000 feet MSL altitude (0.16 psia). The student, in his full pressure suit, is placed in the adjacent lock or compartment, which is called the intermediate lock. This lock is then evacuated to an equivalent pressure to that found at 35,000 feet MSL (3.47 psia). Then, by activating a large electro-pneumatically operated valve, air is allowed to pass from the intermediate compartment into the accumulator compartment. This action is rather impressive to watch since the end result is that the trainee, or more properly the full pressure suit, is exposed to a change in pressure equivalent to flying from 35,000 feet MSL (3.47 psia) to 65,000 feet MSL (0.74 psia) in something under three quarters of one second (the device is actually capable of performing this in 0.25 seconds). The effect on the student is that his suit "inflates" (actually the suit is maintaining existing 35,000 feet pressure and, since less air is around it, it appears to inflate), and the student meanwhile realizes that he has a mobility-restricting appurtenance around him. He will also probably note a beaker of water at approximately 98.6°F, which is placed in the chamber for demonstration purposes, boiling away as though the temperature has been raised to 213° F. This gives him a real appreciation of his full pressure suit, since he has been told, and now realizes that if his body were exposed to an altitude in excess of 62,000 feet MSL (0.89 psia), his blood would be boiling exactly like the water in the beaker.

This training, therefore, demonstrates the use, application and requirement for the full pressure suit in high altitude aircraft operations, since if an aircraft should lose cabin pressure at these altitudes, as a result of hostile action, failure of some cabin surface, or any number of reasons, there just would not be enough time to take remedial action. This incidentally, from all available information, is unfortunately an exact analogy of the situation the three Soyuz 11 Cosmonauts were exposed to in their fateful attempt to return to Earth after a completely successful orbiting space lab mission in late June of this year.

With this rather brief description of three of our physiology-type trainers, you can probably begin to appreciate the difference between a physiology device, and say, an operational flight and weapon system trainer (OF/WST). In the OF/WST the student is essentially taught to reason out and react appropriately as a result of audio-visual type information. In physiological aviation survival training you might say we go a little deeper. In the Dilbert Dunker we strap him in, run him down rails, flip him upside down, and put him under water; in the Ejection Seat we put an explosive charge under his rear, tell him to fire it, while reminding him that if he doesn't hold his back straight he could suffer a fractured spine; and in the Low Pressure Chamber we take his oxygen away and tell him he will not survive unless he uses his equipment properly. This then explains why physiology is different and also the extraordinary part safety must play in this type of device.

PHYSIOLOGICAL ENVIRONMENTS AND ACCIDENT HISTORY

From the preceding discussion, it would appear quite obvious that subjecting human beings to the "exhilerating experiences" of a physiological device must, by necessity, sooner or later result in an injury and, in fact, a good argument can be made for this position. On the other hand, the student or trainee is at a point in life when he could readily be considered in ideal physical condition. The average trainee has been pumped full of health-assuring vaccines, examined from head to foot, has no heart, liver, lung or kidney problems, and probably cannot even exhibit a decent hemorrhoid. The fact is, that, the trainee is probably at the peak of physical condition and at an age where his body can withstand punishment and abuse better than at any time in his life.

What, then, is the reason that accidents happen in a physiological training environment? My experience, over the past nine years, has been that one factor always stands out in every accident. This factor is the total underestimation of the crossing of sciences and fields of technology involved in design, fabrication, maintenance, and utilization of any of the physiological training devices. After all, these devices certainly do not appear to have nearly the complexity of any self-respecting computer. The truth of this situation is, however, quite different. While the computer designer must have an excellent knowledge of state-of-the-art electrical engineering, the engineer working in physiology has almost daily need for, at least, a basic knowledge of electrical engineering, mechanical and structural engineering, including hydraulics and pneumatics, chemistry, physics and in the case of altitude chambers, high altitude physics. Then, to further complicate the situation he must understand how each of these fields affects a living organism. The effect on living organisms is, needless to say, the worst stickler in this requirement. Unfortunately, the engineer or technically oriented man tends to "think at right angles" to the physiologist or medical individual. As a result, a lack of communication is quickly established and the two go their separate ways with no follow-up on the part of the engineer. The engineer complains that no one appreciates his technological breakthrough and the user, in this case the physiologist, thinks it is not esthetically pleasing and something is wrong, but he does not know how to explain it. Meanwhile, the engineer does not follow-up on the device's operation or utilization since he will not be appreciated. Then "bingo" a disaster occurs. This cycle seemingly occurs over and over again to the consternation of everyone, especially the accident victim. That is to say, the one truth in this rather unusual training device field is "Murphy's Law" (anything that can go wrong will go wrong) will prevail.

As an example, take the case of the gentleman who is now considered the father of aviation physiology. During the early 1800's he was concerned with the physiological aspects of high altitudes on living organisms. Not being certain what would happen to a human, ascending from the surface of the earth, he wisely chose one goat and one duck to be put into a gondola below a hot air balloon. The balloon was released and subsequently ascended with the goat and duck. An hour or so later the balloon descended back to earth and the goat was found to be in excellent condition, thereby, proving that a living animal and, in all probability, a human could exist at what was then considered a high altitude. Unfortunately, however, the thought of restraining the goat within the gondola had not been properly considered and the goat had, in fact, not appreciated the experience of being the first goat in free flight. As a result, while the experiment was in all aspects a scientific success, the duck was found dead in the gondola, trampled to death by the goat and, thereby, proving conclusively that "Murphy's Law" existed before the twentieth century, at least for ducks. Since that time there have been a number of similar situations in a physiology training or physiology environment. Some are comical, but unfortunately, many are sad.

On the Device 6EQ2 Ejection Seat Trainer a situation occurred where a young Naval aviator, an Ensign, found that the ejection seat went further up the rails than anticipated. In fact, the seat went all the way to the top of the rails and was teetering back and forth in the breeze balanced precariously by only two of its four restraining mechanisms. Fortunately, the Ensign had a strong heart and no injury resulted. The cause of the incident was probably too much black powder in the cartridge used in an overheated barrel assembly on a very hot day. Shortly, thereafter, a modification was made to the ejection seat firing barrels employing a relief port, which activiated if overpressure from a charge occurred. In the 1960's, a number of accidents have occurred on ejection seat trainers, such as broken toes, when a student's foot hit the simulated instrument panel of the cockpit section of the trainer as the seat moved up the rails, or bruised elbows, when the student's arms hit the side of the cockpit. We even had a barrel assembly explode at a Naval Air Station in our own state of Florida. In each instance,modifications were quickly made and fortunately only one man was seriously injured.

On the Dilbert Dunker, no injury of any consequence is known to have occurred until early last year when we were informed that a Marine pilot at a Marine Corps Air Station sustained fractures of the 6th and 7th cervical vertebra, as well as a badly cut mouth. The history of this accident is a typical "Murphy's Law" situation. In other words, a long series of circumstances just waiting for an accident to happen. The device had been in operation for many years without any apparent problem. At the time, the device had not received any type of quality assurance and inspection, and because of its long history of good operation, had not received any priority for an inspection. The Marines, by their very nature of being good fighting men, did not really have their hearts in water survival training and consequently did not properly perform even routine maintenance on the device. They also had determined that the inertia reel on the ejection seat was too much trouble to pull against each time a student was strapped into the device. As a result, they had pulled the seat shoulder straps out and locked the inertia reel by wedging something in the teeth of the reel. This of course allowed the student to move his upper torso freely in the seat, since his shoulder straps no longer restrained him back into the seat. In addition to this, the two catch assemblies, which are supposed to prevent the cockpit from inverting until being released just before reaching the water, were in such condition that one catch was totally inoperative, and the other so rusty that the Marines admitted having to jump up and down on the cockpit to make it engage, when the carriage was retrieved back to the top of the rails after a ditching run. Add to this a particular day when the usual operating crew were not available and a new crew took over. The result was that the cockpit was not locked down in the carriage, when the student got into the device. After strapping the student in, the carriage was released and almost immediately started to invert. At this point the cable drum operator slammed on the brake abruptly stopping the cable drum, cable and cockpit carriage. This naturally gave the cockpit, which incidentally had reached approximately 90° of its full 180° inverted position, a tremendous jerk, thereby, giving the student what can only be called one of the most confirmed cases of whip lash in history. In this accident everyone was actually lucky. Why lucky? Because if the carriage had continued down the rails in the inverted position, the major part of the cockpit would have cleared the edge of the pool and, along with the section of the student's body from the neck down, gone into the water. But the top of the seat, and from the neck up, the student would have stayed on dry land. Needless to say, immediate "Murphy" proof modifications were initiated and a quality assurance inspection procedure was established. Since that time, several additional safety oriented, but unrelated modifications have been made on this series of devices.

The 9A/9U49 series of Low Pressure Chambers, in the area of safety, present by far the greatest challenge of any physiology training device. To date, we in the Naval aviator training have been extremely fortunate. We have not experienced a single known serious accident in any low pressure training chamber. It might be added, in retrospect, that knowing the scope and purpose of numerous modifications, directives, and procedures, which have been instituted since 1965, would amaze any rational person in that "Murphy's Law" never caused a group fatality in one of these devices. Unfortunately, our counterparts in both NASA and the Air Force were not that lucky. The NASA incident occurred on January 27, 1967, when LCOL Virgil I. Grisom, LCOL Edward H. White II, and LCDR Roger B. Chaffee were burned alive in a physiology environment, resulting from a flash fire aboard Apollo 1, during a launch pad test. This fire was ultimately attributed to electrical arcing in a wiring harness within the capsule. Just four days later, on January 31, 1967, at Brooks Air Force Base, Texas, two airmen met a similar fate. In order to better appreciate the hazards of a fire in a closed compartment, housing personnel in an altitude simulating physiological environment, and specifically in these cases, as in our chambers, an oxygen enriched atmosphere, let me briefly go over the situation that occurred at Brooks.

At about 8:18 AM, on the morning of January 31, 1967, two airmen entered a low pressure chamber for the purpose of conducting tests in the chamber, at an equivalent pressure of 18,000 feet MSL (7.3 psia), in a high oxygen content environment. After about twenty minutes the outer lock in which they were standing had reached the 18,000 foot altitude,and the door was opened between the outer lock and adjacent main lock, which was already at 18,000 feet. The two airmen then entered the main lock to attend to some animals on which the testing was being performed. A few minutes later the crew chief, who was sitting at an instrument panel outside, heard a noise,which to him sounded like an animal cage being dropped inside. He then went to a porthole where he saw fire in the chamber. Immediately, he sounded an alarm and the fire department arrived in two minutes, and two doctors were ready to give aid in approximately two and a half minutes. However, the firemen and doctors were all to no avail. The casualty list--sixteen rabbits, about fifty mice, and two young airmen.

The resulting investigation indicated that the fire had probably been started by one of the airmen stepping on a teflon covered power cord attached to a goose neck lamp which was plugged into a standard 110 vac utility outlet inside the chamber. As a result of stepping on the cord, the cord shorted to the steel to the steel deck with the arc igniting the bottom of the airman's trousers. Experiments have shown that once ignited the airman would have been completely engulfed in flame in a matter of mili-seconds and, assuming combustible materials within the chamber, the entire chamber would have been engulfed in flame within two seconds. What went wrong? In my opinion, somewhere there are some engineers and technicians now spending some sleepless nights because they installed 110 vac utility outlets in a chamber housing combustible materials totally neglecting "Murphy's Law." Truly—an accident waiting to happen.

CONCLUSION — A CHALLENGE OF SAFETY

In conclusion, I would like to summarize this topic by saying--physiological training devices and physiological training environments are different. We deal directly with the human body—not just with replaceable hardware. I would also like to give you the following six tenets of "Murphy's Law":

1. IN ANY FIELD OF SCIENTIFIC ENDEAVOR, ANYTHING THAT CAN GO WRONG, WILL GO WRONG.

2. LEFT TO THEMSELVES, THINGS ALWAYS GO FROM BAD TO WORSE.

3. IF THERE IS A POSSIBILITY OF SEVERAL THINGS GOING WRONG, THE ONE THAT WILL GO WRONG, IS THE ONE THAT WILL DO THE MOST DAMAGE.

4. NATURE ALWAYS SIDES WITH THE HIDDEN FLAW.

5. MOTHER NATURE IS A BITCH.

6. IF EVERYTHING SEEMS TO BE GOING WELL, YOU HAVE OBVIOUSLY OVERLOOKED SOMETHING.

Finally, I would plead with you, that when dealing with Physiological Training Devices, always "THINK MURPHY".

SESSION VI

Thursday, 17 February 1972

Chairman: Mr. Harold Rosenblum
Deputy Director of Engineering
Naval Training Device Center

AUTOMATED GCA-FINAL APPROACH TRAINING

DR. J. P. CHARLES AND MR. R. M. JOHNSON
LOGICON, INC.

Recognizing that recent results from training research and development programs as well as from advanced digital technology could contribute to the solution of training problems, the NAVTRADEVCEN in 1969 initiated a program to test the feasibility of implementing some of these advances.

As part of this effort, LOGICON, INC. analyzed the feasibility of automating portions of weapon system trainers (WST) and prepared some design guides to illustrate implementation on selected flight profile segments. The F-4 trainer was chosen as a sample case. The initial effort involved a survey of typical trainers in operational use. This review of on-going training utilizing WST's concluded that in large:

- WST's were being used primarily for cockpit orientation and procedures training.
- There was a lack of a well-defined approach for utilizing WST's.
- There was a lack of performance criteria and measurement.
- The instructor's role was not well-defined and their approach to training varied widely, especially in student evaluation.

The study indicated that the major technical problems in automated training involve:

- The development of computer programs to evaluate student performance and restructure the training course in real-time.
- The implementation of computer control of all training steps and functions.

The next effort undertaken, by LOGICON, INC. was to demonstrate technical feasibility, the problem being stated as one of implementing sufficient automated weapon system training to demonstrate technical feasibility in terms of computer programs and crew station development, within realistic and practical constraints.

The initial task involving a review of feasible simulators for the test, resulted in the selection of the Training Device Computing System (TRADEC System) at the Naval Training Device Center. This system, which was designed for Research and Development efforts, has the flexibility required for experimental tasks, and most importantly, could be modified and scheduled relatively easily.

Once the TRADEC System had been selected, the training task was bounded in scope and content. The TRADEC System includes a simulated single seat fighter type aircraft. The F-4 aerodynamic equations are utilized. Figure 1, is a block diagram of the major subsystems. The ones of particular interest include the motion system and the COGNITRONICS speechmaker. The latter device assembles a fixed vocabulary into phrases and sentences under computer control. The motion system is driven by the F-4 program contained in the computer. Thus, the TRADEC System constrained the training task to a basic fighter aircraft task with oral command capability. Instrument flight would be required since visual projection equipment is not installed.

A review of the flight segments analyzed in the earlier LOGICON study clearly indicated that the Ground Controlled Approach (GCA) was the most logical task to employ since:

- The task requires an elementary cockpit; i.e., no navigation or flight director system.
- The task is performed under instrument flight conditions.
- The task is a common operational task of fighter aircraft and is of relatively short duration.

The COGNITRONICS Multiplex Speechmaker provided the solution to the GCA voice command input requirement.

Emergency procedures, compatible with the GCA, were selected for additional demonstration tasks. A review of F-4 aircraft emergencies resulted in the selection of two: (1) single engine failure; and, (2) communication failure as feasible for implementation and compatible with the GCA task.

Potential student populations were reviewed. The requirements for a reasonable testing period and meaningful results for weapon system training for operational application dictated the use of qualified military pilots as the primary group.

An analysis of the GCA task was conducted to identify the performance criteria, performance measures, task structure, typical operational environment, and task difficulty factors. For example, standard terminology was collected and tapes of actual F-4 GCA's were recorded and reviewed. Handbooks on the F-4 and GCA Systems, including the SPN-35 and SPN-42 systems, were studied.

The complete GCA includes both a vectoring mode (Airport Surveillance Radar (ASR)) and a precision approach mode (Precision Approach Radar (PAR)). It soon became clear that the vector mode, although not technically difficult to mechanize, would involve extensive modification to the F-4 software. Therefore, the final approach phase, PAR, was isolated for the flight task.

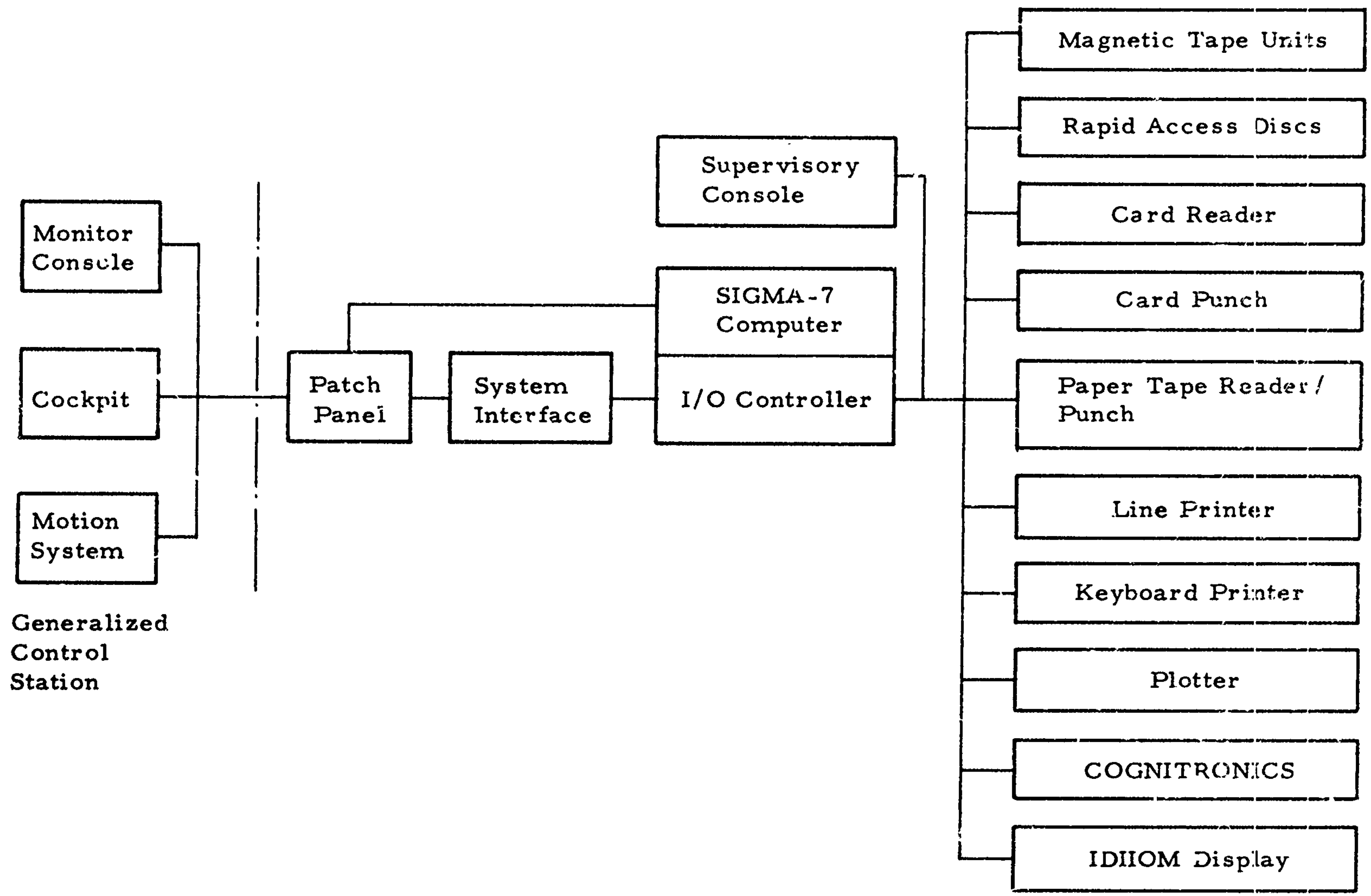

Figure 1. TRADEC System

Functional descriptions provided the foundation for the design and development of the computer program and training program. The end product was a design package which was used to implement the demonstration program. It included:

- A detailed description of the test to be performed to demonstrate the automated training techniques.
- The design and development of the software required for the demonstration.
- Preparation of training schedules, data forms, and student briefing lectures.
- Specification of the required changes to the existing TRADEC hardware/software to properly interface the proposed demonstration program.
- The design of a test plan to adequately check out both the experimental concepts and the program itself.

Three design tasks were conducted. The first involved the development of a sequence of GCA's of increasing difficulty; the second involved design of a system for scheduling the GCA; and the third involved development of a measurement system.

A training course consisting of 38 different runs for GCA training and five for emergency procedures was designed. The analysis of the GCA requirements had produced three major task difficulty factors. These were changes in aircraft weight and drag, atmospheric turbulence, and runway wind conditions. Five conditions and levels for each factor were selected. All reflected F-4 operational capability.

An adaptive logic program was developed to permit the student to complete the course in accordance with his ability. Figure 1 is a flow diagram of the logic developed. The procedure is actually "adaptive-adaptive" since a series of successful runs can accelerate the schedule.

A variety of performance measurements were investigated ranging from control stick displacements and rates to vehicle angles and rates to GCA errors. As discussed earlier, interpretation becomes difficult for all but direct system performance measures. Fortunately, the GCA has very definitive performance requirements. Therefore, measures related to operational performance were feasible. Two separate scores were developed. The first reflected performance during the run. The second reflected offset position relative to the runway at the conclusion of the control phase of the PAR.

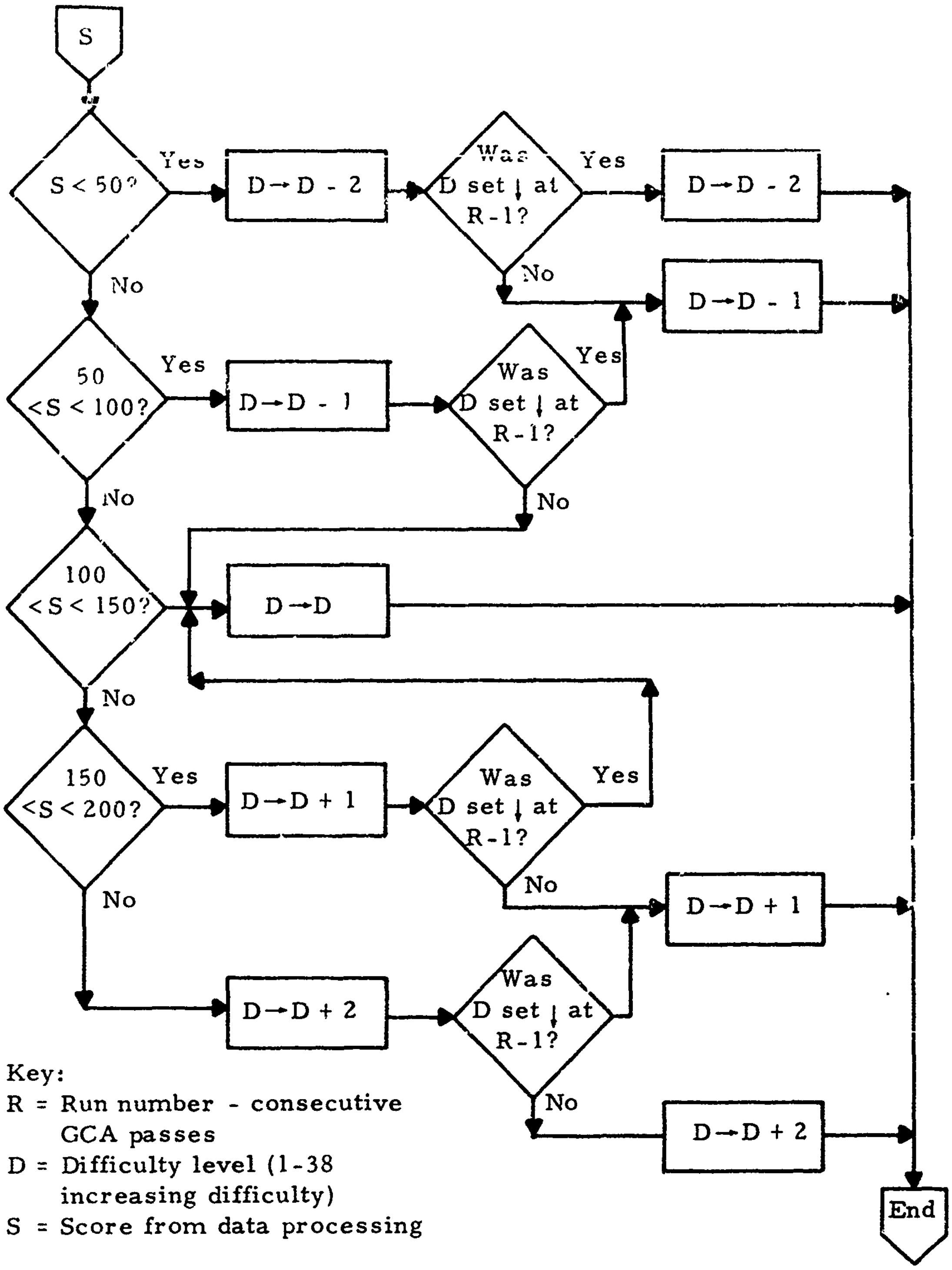

Figure 2. Adaptive Logic Flow Chart

Approach path performance was measured in terms of position error and angle of attack at a one second rate while on final approach. Final performance was measured in terms of actual position with respect to the glide path at the time of passing through final "gate". Five measures were taken:

1. Lateral displacement in feet from the approach course centerline.

2. Vertical displacement in feet from the glide slope centerline.

3. Angle of attack error in units from optimum.

4. Rate of heading change in degrees per second.

5. Rate of angle of attack change in units per second.

These measures resulted in 15 path measures and 5 gate measures. These were combined to provide a single score for input to the adaptive scheduling plan. In effect, a path score was computed for all runs. If successful, a gate score was computed and the path and gate scores were combined for a total run score. If the run terminated in a wave-off or a crash, the path score was adjusted to compensate for the proportion of the run completed.

The original constraints imposed on software design reflected the requirement for compatibility with the F-4 simulation program, especially in cycle time, and with the TRADEC System capability in general. Since the time remaining in the computation cycle was limited, it became clear that an executive program would be essential and that a modular approach to the program would be optimum. The executive program was required to monitor and control execution of the modules and provide the interface with the existing TRADEC software. Other functions of the executive program included:

- Monitor inputs
- Direct outputs and feedback parameters
- Control communications between modules
- Transmit data between operator and program
- Schedule events
- Establish priorities
- Allocate memory for the modules
- Provide procedures for error recovery
- Provide timing and accounting parameters.

The basic design of the executive program involved a foreground and background mode. The advantages of this design included:

- Program modules were list ordered by execution priority.
- The Executive Routines were independent of the other modules.
- Priority of any Foregound or Background (F/B) program was easily changed by reordering the program lists.
- Active modules could activate or deactivate any other F/B program.
- Inactive modules were easily bypassed.
- New modules were added by simply inserting the program and a one-word linkage to the list.
- Obsolete modules were removed by simply removing the program module and the one-word linkage.
- Modules could be virtually removed by deleting the one-word linkage.
- Foregound modules could be transferred to Background (and vice versa) by interchange of the one-word linkage.

These features are obviously desirable for an advanced program where flexibility is essential. Figure 3 illustrates the basic hardware/software system flow.

A total of 12 Navy and Air Force F-4 pilots were "trained" during the test phase. Additional data on two nonpilots was accomulated for comparison.

All of the 12 F-4 pilots were on operational flight status with an F-4 squadron. The pilots were only available for one day because of operational and training commitments. Therefore, the training plan was a "pilot-demand" schedule in which the pilots flew GCA runs until they were tired or wanted to rest. Two pilots were scheduled per day so that they could alternate flying and resting. Training began about 0900 and continued as late as the pilots were willing to fly or until they completed the course. This procedure resulted in a median number of trials per session of seven.

Five of the 12 pilots completed the GCA course in terms of reaching the most difficult level of the syllabus. The median number of runs for these pilots was 26 as opposed to a median of 30 for the pilots, who did not complete the course, because of time limitations or fatigue.

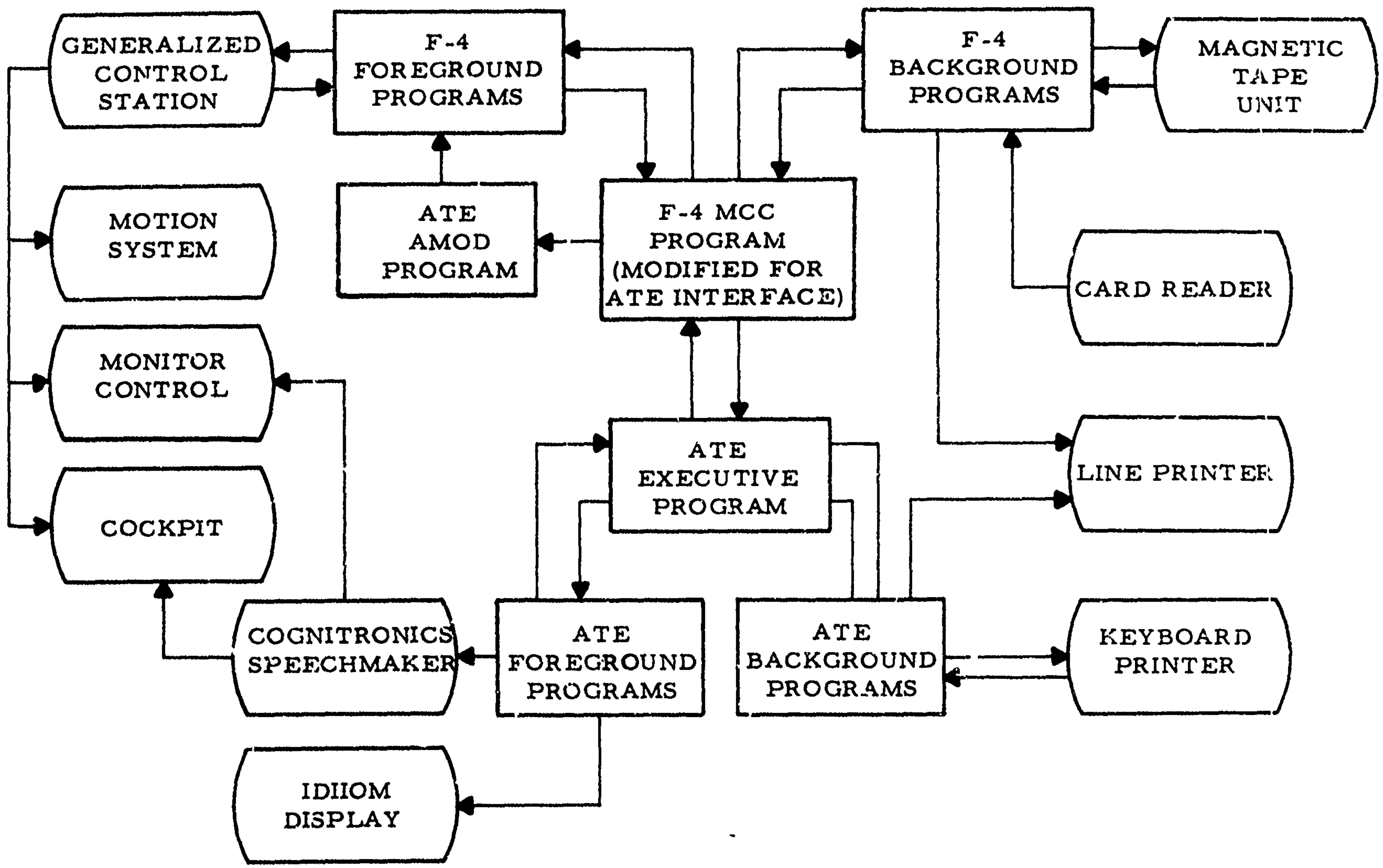

Figure 3. F-4/ATE Basic Hardware/Software Systems

Plots of the progress of each pilot as a function of the run number and difficulty level reached were made. Figure 4 is a sample plot.

It was concluded that the technical feasibility of the concept of automated instruction in a weapons system trainer has been demonstrated and that the state-of-the-art of digital systems and training methodology appears adequate for implementation of automated training.

Based on the limited nature of the tests concluded, the following additional conclusions are suggested:

- Automated flight training is acceptable to pilots.
- Adaptive training techniques can be implemented and appear effective and acceptable by the students.
- Voice generation techniques are adequate for simulation purposes.
- Pragmatic solutions to student performance measurement are feasible and prove useful for training control. Total system performance criteria, however, must still be established and measured.

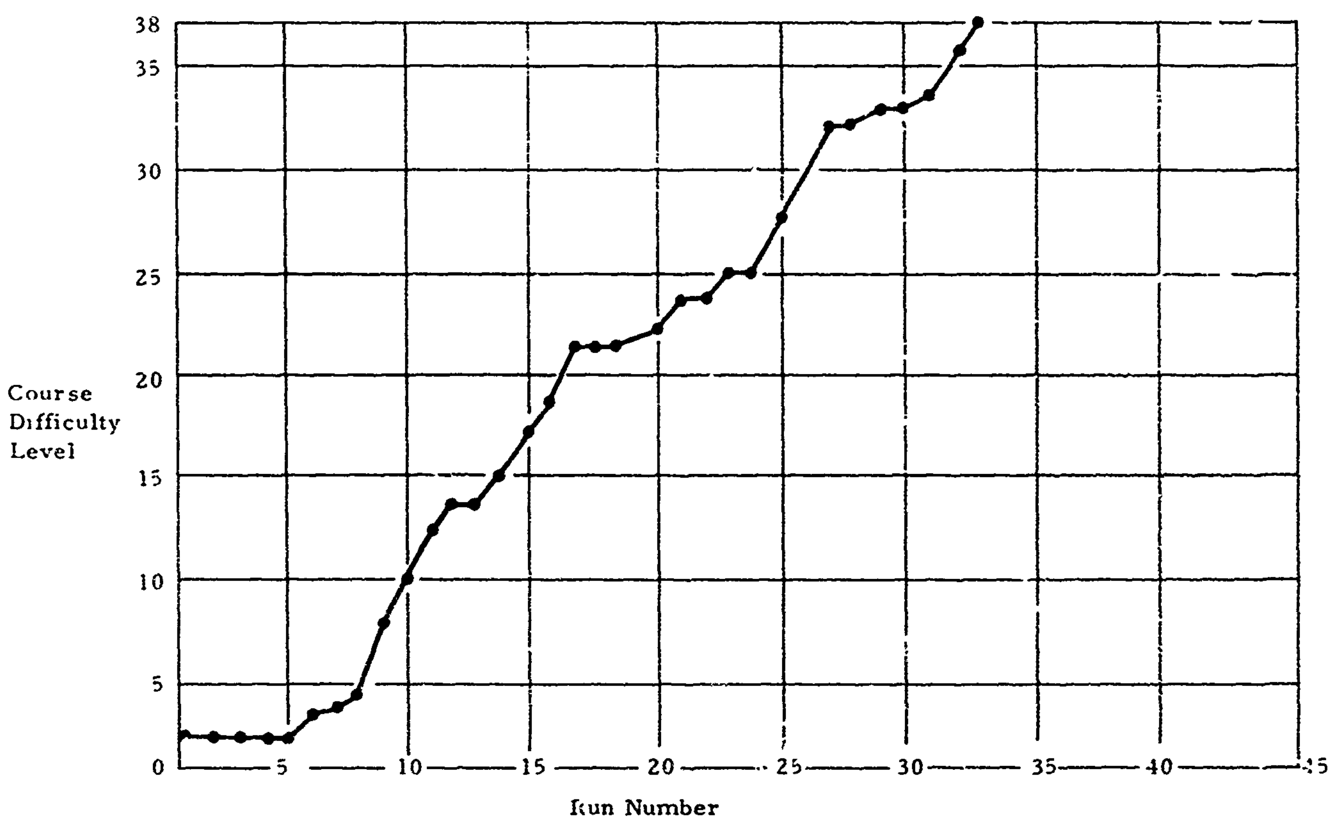

Figure 4. Sample Pilot Data

PAPERS PUBLISHED
BUT
NOT PRESENTED

ROLE OF DIGITAL COMPUTER
MODELS IN TRAINING DEVICE DESIGN
AND PERFORMANCE MEASURES

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The need to evaluate student and instructor workload with more precision during training device design increases with the cost and complexity of new systems. Paper and pencil methods are adequate to evaluate total student and instructor workload early in the design, but have weaknesses when applied to task distributions, probability effects, and simultaneous events. Computer methods have been developed to give equipment designers early quantitative data on student and instructor workload capability (Asiala, 1969; Chubb et al, 1970; Clausen et al, 1968; Nelson and Jackson, 1968: Siegel and Wolf, 1969; and Topmiller, 1968). This paper describes a model which provides more realistic student and instructor workload data. The model has these advantages compared to other available models in that it:

- o Provides required core independent of the number of requested replications
- o Supplies visual, right and left hand, feet, communication, and auditory and visual information processing loadings besides the total task loading
- o Considers simultaneous tasks
- o Provides task distribution
- o Simulates human failure rates and learning curve variations.

Analytical and computer techniques are combined in the model to aid in determining student and instructor display and control requirements, station configurations, and allocation of tasks. In addition, it provides the effect of automated and manual operations on task loading, queuing delays and reliability, the impact of diverse add-on requirements, and the performance measurement criteria.

BACKGROUND

Monte Carlo simulation is a useful technique for improving decisions about military systems and operations. With increasing system complexity, simulation is essential for understanding system elements and their interactions. Some large, complex training systems cannot be examined directly because:

- o Proposed system in development phase such as the F-14, F-15, and Harpoon
- o Experimentation with real system difficult and costly
- o Experimentation involves risk to human life such as high g's and radiation.

The Siegel-Wolf (1969) and other models have some limitations for weapon system applications as we discovered on our F-14 and F-15 early design

studies. The McDonnell Douglas Corporation (MDC) Pilot Simulation Model (Asiala, 1969) eliminates these limitations. Our Advanced Multi-Man Crew Digital Simulation Model is an extension of this MDC Pilot Simulation Model FORTRAN program. It is generalized to the extent that it can be used to model virtually any instructors/students activity network.

Specifically, we have a stochastic digital model with variable and parallel flow logic to simulate multi-man workload. Input and output data procedures are described in sufficient detail for direct application to student/instructor interfaces. The simulation model is programmed on the IBM S/360 computer and utilizes the PL/1 language (Pollack and Sterling, 1969; IBM, GC28-8201 and -6594). PL/1 was chosen as the language because it possesses the power and flexibility required to implement simulation models of large and complex systems, and it allows dynamic storage allocation and pointer-connected set manipulation, which are necessary mechanisms for efficiently implementing event-oriented simulation models.

Since this simulation model has parallel flow capability, the training task logic varies the sequence of tasks for the instructors and students. This variation is controlled by the probabilities associated with the training task or event logic. Each new training task logic is established by the input cards without revising the integral parts of the program. The model has these properties:

- System independence
- Ease of formulation and change
- Minimum requirements of system assumptions
- Static and dynamic system performance information .

MODEL

The two most widely used programming languages for event-oriented simulation models are GPSS (IBM, 20-0304) and SIMSCRIPT (Markowitz, 1969). Experience gained through using both languages has shown that GPSS is an excellent language for small simulation studies, where the primary concern is the minimization of the manhours required for programming. However, GPSS does not possess the flexibility and efficiency required for constructing models of large, complex systems. Whenever language flexibility is required and whenever a concern exists regarding run time and storage requirements, than a more powerful language, such as SIMSCRIPT, is more suitable than GPSS. The complexity of a multi-man crew simulation model requires the use of a highly flexible language such as SIMSCRIPT. However, early SIMSCRIPT compilers were unreliable. Recent versions are reliable but costly. The solution to this problem is to use another language with SIMSCRIPT flexibility but also including mechanisms for efficiently implementing simulation models. The best mechanisms are pointer-connected set manipulation and dynamic storage allocation. One approach, used on F-15 Pilot Simulation Model (Asiala, 1969), is to use FORTRAN with Douglas SIMSYS package of subroutines (Brinsley, 1967). PL/1 is another suitable language and was utilized for our Multi-Man Model because it was more efficient than a FORTRAN program in terms of run time, and SIMSYS dynamic storage allocation technique restricted the size of storage pool to 43,000 words, a severe limitation for large models.

Model Subroutines - The primary routines are MAIN, INPUT, STRTREP, EVENT AND REPORT. MAIN controls the simulation by calling EVENT routines and updating simulation clock. INPUT reads in and checks user supplier input data and creates block entities. STRTREP begins a replication. When an event notice is removed from the calendar, the EVENT routine is activated by MAIN routine. EVENT also creates event notices for block output 1, through predecessors. REPORT summarizes statistics at end of run and produces user-requested reports, and generates a plot tape for the CALCOMP plotter.

The nine secondary-service routines are:

1. START - Creates an event notice and places it on the calendar and is called by EVENT and STRTREP.

2. FIL-FST - Files an entity at the beginning of a pointer-connected set.

3. FIL-LST - Files an entity at the end of a pointer-connected set.

4. FIL-RNK - Files an entity into a ranked pointer-connected set.

5. RMV-FST - Removes the first entity in a pointer-connected set and returns its pointer.

6. RMV-LST - Removes the last entity in a pointer-connected set and returns its pointer.

7. RMV-SPC - Removes from the set if entity is a member of a pointer-connected set.

8. CAUSE - Files an event notice entity into the calendar.

9. CANCEL - Removes a member event notice entity from the calendar.

Simulation Model Operational Procedures - The operational or training network consists of one or more connected sets of blocks. A block consists of a set of task elements performed by a crewmember, student or instructor. Based on our FORTRAN simulation model experience, the block structure illustrated in figure 1.was developed for our Multi-Man Model. This block structure consists of time delays 1 and 2, task elements 1 and 2, information processing task element, equipment probabilities 1 and 2, human probabilities 1, 2, and 3 (Askren and Regulinski, 1971), and mission recycle probability.

Simulation Model Input Data - The model input data is categorized into system and block data. The system data applies to all blocks. The "GET LIST" cption of PL/1 allows the input data to be free format. The only restriction is that each data item must be separated by one or more blanks. This process is an advantage over the FORTRAN card boundary approach. These system data are provided at a minimum:

- Network title
- Number of replications
- Number of blocks
- Equipment probability switch

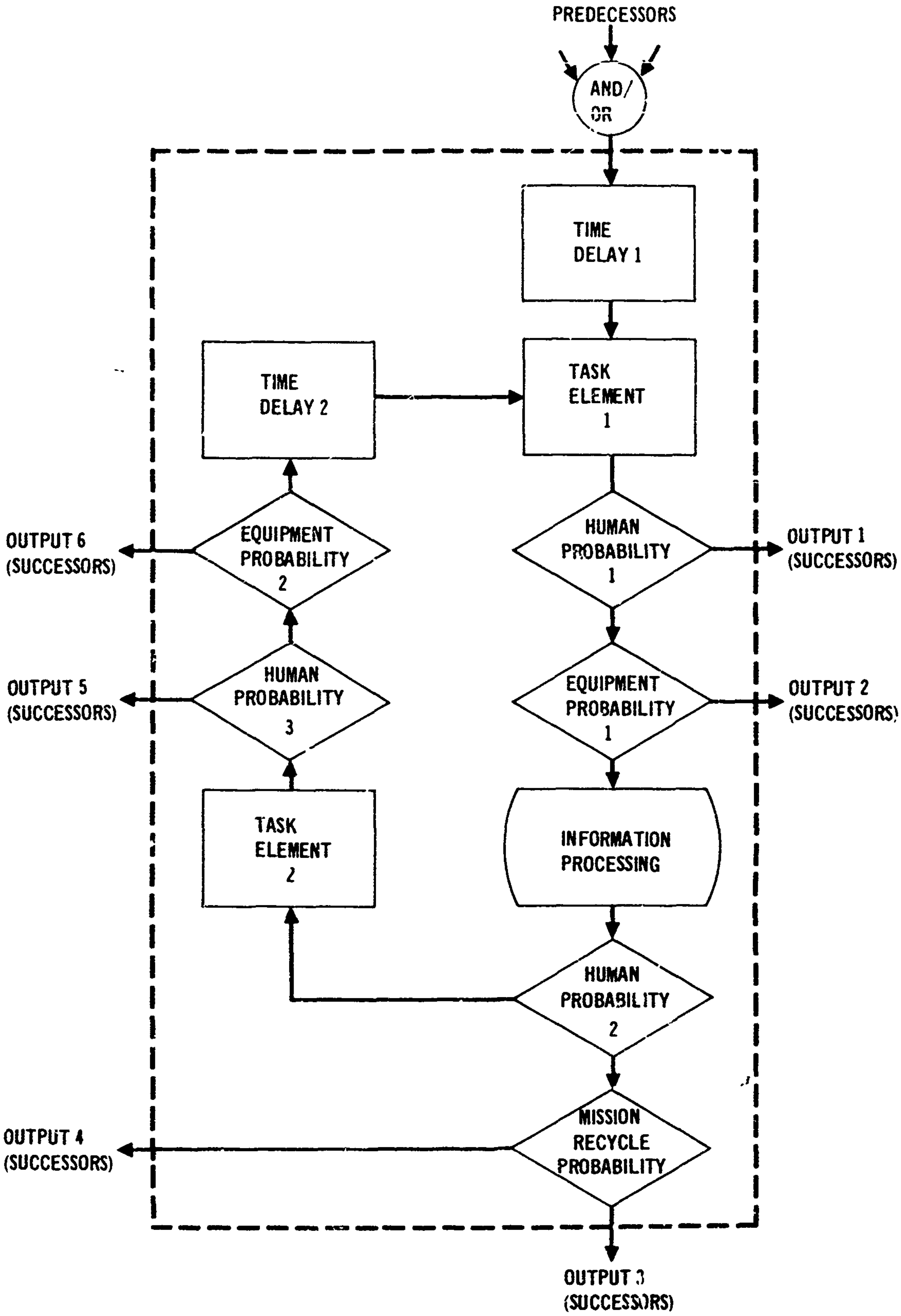

Figure 1. Block Structure

- Number of individuals
- Individual titles
- Type of distribution
- Calendar switch
- Number of equipment
- Equipment title
- Number of plots and plot selection switches.

Each block in the network contains these 12 data elements: Task block title and number; number of task block predecessors; and/or acceptance switch; individual assigned to block; task to be interrupted (optional); sensory mode data for task 1 and 2 elements; equipment probabilities; human probability factors; mission recycle probability; recycle limit; task 1, information processing, and task 2 elements mean and standard deviation; and equipment associated with task 1 and 2 elements. Temperature, stress, cohesiveness, altitude, and undefined (spare) environmental factors can be provided as input variables.

Our experience in coding data to describe large networks has shown that, in many cases, sets of similar blocks appear. Our major loop approach somewhat relieves the problem of coding similar blocks. However, there still remain cases where a similar block must be coded several times. The MDC model has the capability for the user to create a library of standard blocks. Therefore, when preparing input data for a simulation run, blocks are pulled from the library, modified to any extent desired, and used to augment the sets of blocks described in the card data deck.

In order to create and update the library, a file maintenance program has been coded in PL/1. This program is completely separate from the PL/1 simulation program. The maintenance program performs the following functions:

- Create new library, and produce printed library listing
- Delete specific blocks from existing library, and produce updated listing
- Add blocks to existing library, and produce updated listing
- Delete and add blocks to existing library in the same tune, and produce updated listing
- Produce listing of existing library.

Simulation Model Output Data - The detailed and summary output data are a check of input data, error message, optional calendar printout, network summary data per replication, network activity plots (up to 10), and statistical summaries such as mean, standard deviation, and measures of skewness and kurtosis. Timeline CALCOMP subroutines are incorporated. The mean start and stop times are available for each occurrence of task 1, information processing and task 2 elements for each task block in the network. This summarized information can be plotted on an off-line CALCOMP plotter. Plot selection

switches used to control the contents of each plot are in figure 2. Figure 3 illustrates a typical plot. These data are provided in two-dimensional plots and have been utilized for detection of potential crew, student or instructor task overlaps. Potential task overlaps are detected from the plots for average task start and stop times up to 100 mission replications. These task overlap conditions have been analyzed for consideration in the following classification categories:

SELECTION NUMBER	CARD INPUT DATA	PLOT
1	0	ALL INDIVIDUALS
	1	INDIVIDUAL ONE
	2	INDIVIDUAL TWO
	3	INDIVIDUAL THREE
	4	INDIVIDUAL FOUR
	5	INDIVIDUAL FIVE
	.	.
	.	.
	.	.
	10	INDIVIDUAL TEN
2	A	ALL SENSORY MODES
	V	VISUAL SENSORY MODE
	R	RIGHT HAND SENSORY MODE
	L	LEFT HAND SENSORY MODE
	F	FEET SENSORY MODE
	C	COMMUNICATIONS SENSORY MODE
	I	INFORMATION PROCESSING SENSORY MODE
3	0	ALL EQUIPMENT
	1	EQUIPMENT 1
	2	EQUIPMENT 2
	.	.
	.	.
	.	.
	999	EQUIPMENT 999

Figure 2. Plot Selection Switches

- o Potential task overload
- o Sufficient time for shift of task
- o Left hand required for normal right hand operation
- o Processes more than one signal
- o Overlap due to computerized sampling average for mission replications.

Figure 3 also shows that the technique is useful for the establishment of performance measurement criteria. Sufficient output data are available for construction of individual task error ratio curve as a function of trials established by part task simulation. This type of plot is in figure 4.

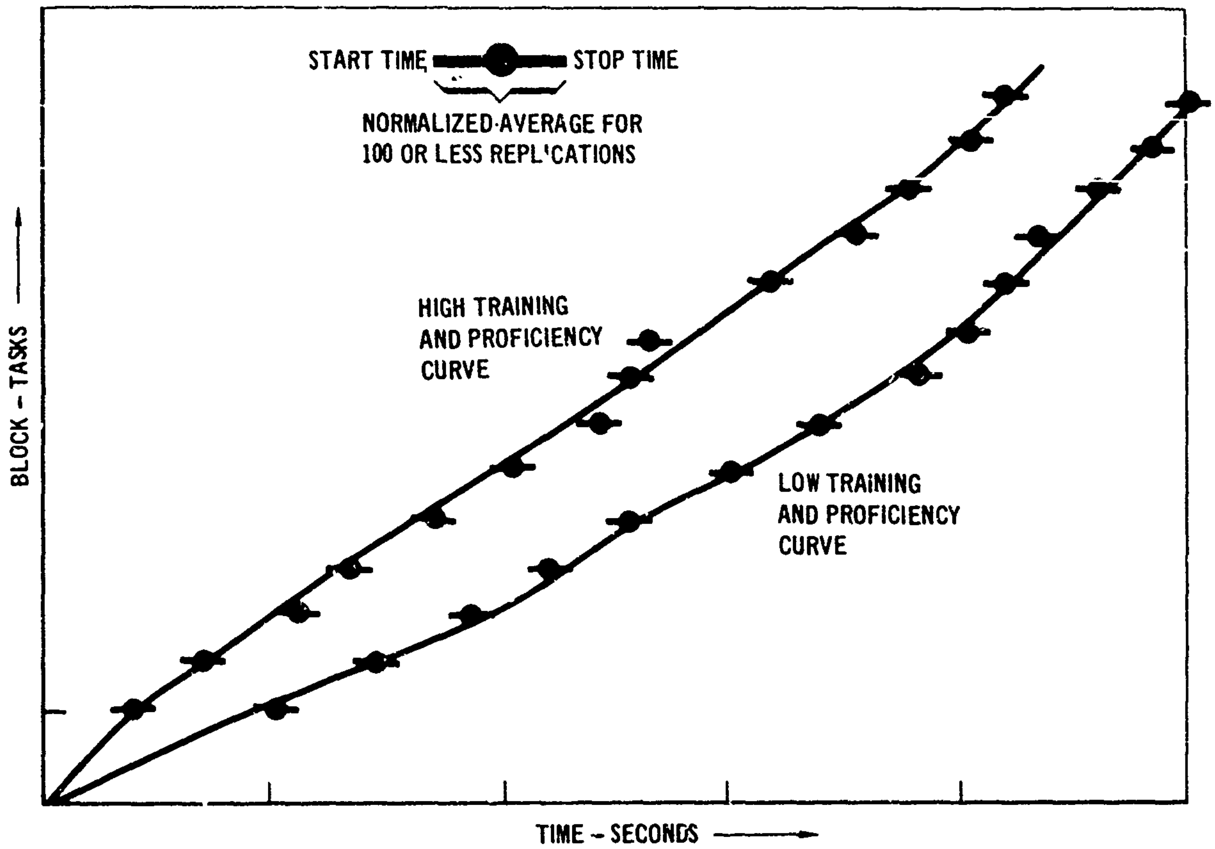

Figure 3. Typical Time-Line Calcomp Plot

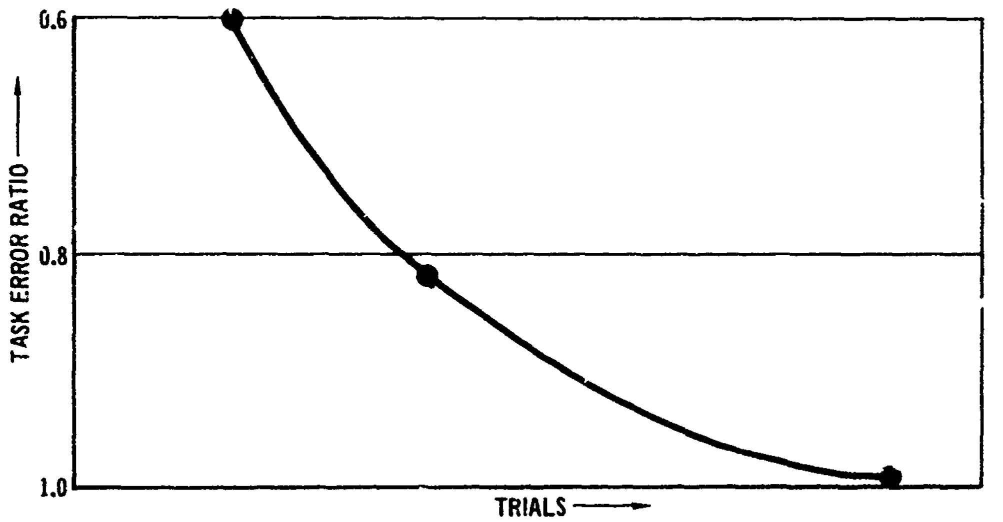

Figure 4. Typical Individual Task Error Ratio vs Trials

Plots illustrating the delays (queuing information) experienced by students due to instructor overload are also provided as a function of variable automatic versus manual diagnosis.

SUMMARY

Our model incorporates at least the following considerations in generating the quantitative criteria of mission, crew, student, or instructor performance:

- o Each simulated individual workload as a function of time available and remaining tasks
- o Impact of individual interaction and cohesiveness
- o Independent proficiency of each individual
- o Mission or session duration variable influencing task criticality
- o Intercommunication constraints among individuals
- o Effects of individual decisions.

The technique evaluates all performance data within the context of objectives or contingency events to derive an operational or training definition of minimum acceptable level of task performance, in terms of explicit criterion values. This validated model is useful for selection of display and control configuration from many alternatives, establishment of display and control requirements based on performance and utilization, and identification of efficient and practical group sizing for operational and training situations. It also establishes automated and manual operations affects on task loading and reliability, identifies performance measurement criteria, and establishes diverse add-on requirements impact on operational and training activities.

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MEASUREMENT OF AIR TRAFFIC CONTROLLER PERFORMANCE

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To supply technical support for the concept formulation of an Air Traffic Management System, a test vehicle was developed to evaluate certain automated enroute air traffic control concepts in a tactical environment. Designated the Semiautomatic Flight Operations Center (SAFOC), it was evaluated by its ability to control simulated Army air traffic, flying according to realistic tactical scenarios. The target simulators at the National Aviation Facility Experimental Center (NAFEC) provided the air traffic input, and automatic data collection techniques gathered the output.

One of the primary purposes of the evaluation was to test the ability of air traffic controllers to work with automated equipment while retaining the final decision on any control commands. It is felt that the data collection, reduction, and evaluation techniques to be described in this paper are of general interest in establishing and quantifying human performance measures in a semi-automated environment.

The technical objectives of the enroute test bed are:

1. To regulate Army air traffic under instrument flight rules

2. To provide flight following capability under visual flight rules

3. To improve information transfer among system elements and units being supported

4. To provide computer facilities to automatically analyze air traffic data for display and decision-making by an operator

5. To provide a means for making commanders aware of the current air traffic situation for overall tactical planning

6. To perform specific functions required for air traffic regulation

SYSTEM FUNCTIONS

SAFOC includes data processing, radar processing, display, and manual backup subsystems to provide the following capabilities:

1. Flight data processing
2. Flight following
3. Flight handoff
4. Identification assistance
5. Emergency assistance
6. Air/ground coordination
7. Ground/ground coordination

SAFOC provides the following methods of flight tracking: digital data link, radar beacon, radar skin return, and flight plan following.

SAFOC TEST CONFIGURATION

Figure 1 shows the test operations and information flow diagram. The scenario generator program generates scenarios and scripts based on realistic scenarios. The scripts are followed by pilots, who simulate actual flights, using target generators which are part of NAFEC's data link simulation.

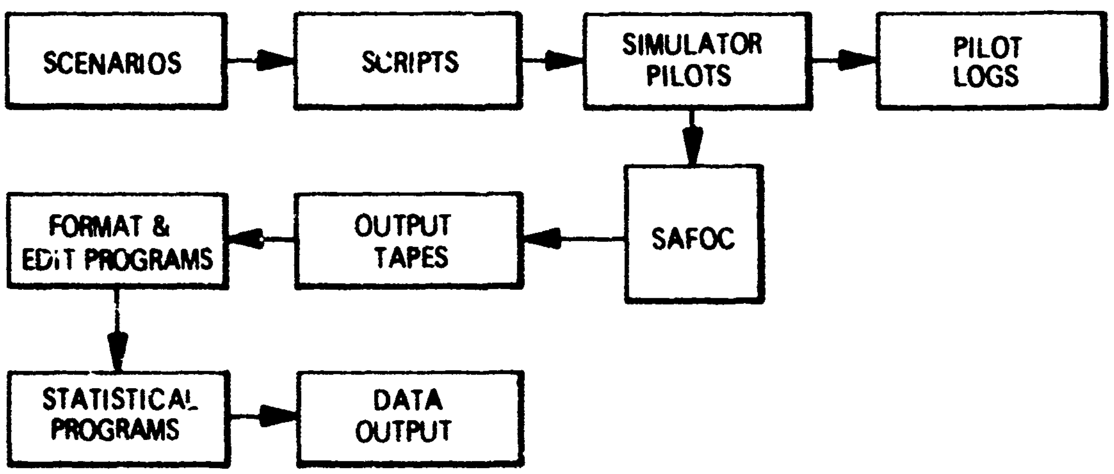

Figure 1. SAFOC Test Operations and Information Flow Diagram

Using a predetermined, operational-procedural mode, the system controls the simulated flights and produces exhaustive time histories on magnetic tape. These histories include all actions performed by the equipment or by the controller. The raw output data tape and the target generator history tape are processed using a series of formatting and editing programs, after which statistical programs generate the desired data output.

Evaluation of the SAFOC consists of a series of tests including Preliminary testing for familiarization with the equipment and training of controllers; Phase I testing to determine the best operational method, to rank controller performance, and to find the system performance measures and effectiveness measures; and Phase II testing to evaluate system and controller performance, using realistic tactical scenarios, and to recommend changes to optimize the SAFOC.

PHASE I TEST PLAN*

To evaluate controller performance and to determine the best method for operating the SAFOC, a series of tests was planned and conducted using the NAFEC simulation facility. The tests consist of a series of scenarios of three different traffic levels. Each of four controller teams operate the SAFOC according to four different operational-procedural combinations. The outputs, consisting of system effectiveness measures, are ranked to determine the best operational-procedural mode. Figure 2 shows this experimental design.

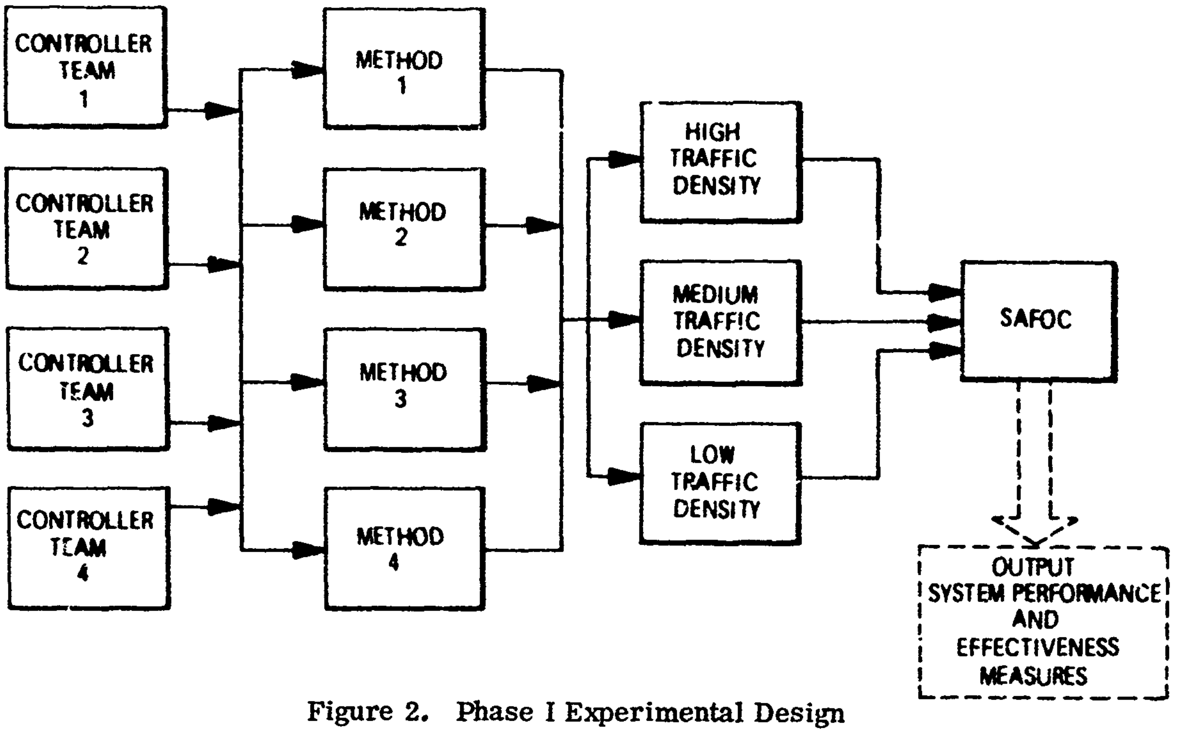

Figure 2. Phase I Experimental Design

* "Phase I Test Plan for a Semiautomatic Flight Operations Center (Design of Experiments Program)", July 1, 1970, Contract No. DAAB07-69-C-0040.

SYSTEM PERFORMANCE MEASURES. Evaluate the individual items which, in total, influence the system effectiveness. The performance measures represent, for example, the actual contributors to total workload, and it is through improvements in the performance measures that the effectiveness measures can be improved.

1. Time to perform each service
2. Service rate
3. Waiting time for service
4. Event time history
5. False dismissal probability
6. Actual density history
7. Queue lengths
8. Typewriter errors
9. Near miss history
10. Communication time history
11. Number of impossible requests
12. Altitude change history
13. Closest approach history

SYSTEM EFFECTIVENESS MEASURES. (SEMs) are used to provide relative rankings of the operational-procedural modes and to evaluate relative controller team performance. The following measures are chosen because they represent the characteristics most important to the user:

Safety is the number of near misses per aircraft mile flown.

Controller workload is the total time for all flight servicing.

Communications workload is the total time spent in communications.

Delays are the actual departure time delay from the planned departure time. Delays are important in a tactical situation.

Throughput is defined as the actual number of flights entered during steady state divided by the number of entries planned in that time.

Capacity is the peak flight density safely handled by the system.

Uncontrolled time is the total time of flights within the control area without being controlled by the system.

MATHEMATICAL MODEL AND CONTROLLER TEAM PERFORMANCE

It is possible to rank the controllers on some measurable characteristics. For this ranking the C teams in R replications using different but equivalent scenarios are used. In essence, random trials of the controllers' ability to handle repeated scenarios are performed to determine whether the controllers are significantly different in their abilities. If they are different, they are ranked in order of their abilities to determine those needing additional training.

Table 1 shows the symbology of the effects (effectiveness measures) resulting from replications of different scenarios, by each controller, and indicates the sums to be performed. Table 2 shows the usual analysis of variance for a two-way classification based on a mixed-model of fixed teams and random samples from the hypothetical population of replication observations.

When the scenarios are run, the data (such as the workload times of each controller) consisting of the X_{ij}'s shown in table 1 is operated on by performing the column and row sums, followed by the operations shown in table 2. Then the sums of squares and mean squares shown in table 2 are computed. The F ratio is computed:

$$(1) \quad F = \frac{S_2 (R - 1)}{S_3}$$

TABLE 1. EFFECTS OF REPLICATIONS

TEAMS						
Replications	1	2	.	.	C	Row Sum
1	X_{11}	X_{12}	.	.	X_{1C}	$\sum_{j}^{C} X_{ij} = C\bar{X}_{1.}$
2	X_{21}	X_{22}	.	.	X_{2C}	$\sum_{j}^{C} X_{2j} = C\bar{X}_{2.}$
.	.	.	.	.	.	
.	.	.	.	.	.	
R	X_{R1}	X_{R2}	.	.	X_{RC}	$\sum_{j}^{C} X_{Rj} = C\bar{X}_{R.}$
Column Sum	$R\bar{X}_{.1} = \sum_{i}^{R} X_{i1}$	$\sum_{i}^{R} X_{i2} = R\bar{X}_{.2}$			$R\bar{X}_{.C} = \sum_{i}^{R} X_{iC}$	$\sum_{i}^{R}\sum_{j}^{C} X_{ij} = RC\bar{X}_{..}$

C = Number of teams
R = Number of replications

TABLE 2. ANALYSIS OF VARIANCE FOR A TWO-WAY CLASSIFICATION

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE
Replications	$S_1 = \sum_{i}^{R} (\bar{X}_{i.} - \bar{X}_{..})^2$	R-1	$S_1/(R-1)$
Teams	$S_2 = \sum_{j}^{C} (\bar{X}_{.j} - \bar{X}_{..})^2$	C-1	$S_2/(C-1)$
Error	$S_3 = \sum_{i}^{R}\sum_{j}^{C} (X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X}_{..})^2$	(R-1) (C-1)	$S_3/(R-1)(C-1)$
TOTALS	$S_4 = \sum_{i}^{R}\sum_{j}^{C} (X_{ij} - \bar{X}_{..})^2$	RC-1	---

where S_2, S_3 and R are defined in table 2. Reject the null hypothesis of no team difference if (1) exceeds the α point of the F distribution with (C-1) and (R-1) (C-1) degrees of freedom. For example, if α equals 0.05, C equals four and R equals two, then the critical value is:

(2) $F_{0,\ 0.05,\ 3,\ 3} = 9.28$

If the computed value of F was larger than 9.28 one could say that the controllers performed their tasks with significantly different capabilities and that similar tests would repeat this conclusion with a 5 percent risk of being in error.

If we wish to rank each of the teams with respect to every other team, Tukey's multiple comparison procedure can be used. This consists of taking the difference between every pair of team performance means computed during the test:

(3) $B_1 - B_2 = Z_1$

$B_1 - B_3 = Z_2$

$B_1 - B_4 = Z_3$

$B_2 - B_3 = Z_4$

$B_3 - B_4 = Z_6$

where B_ℓ is the mean workload performance parameter of ℓth team

$$B_\ell = \frac{1}{R} \sum_i^R X_{i\ell}$$

We then compute:

(4) $Z_i - \frac{S}{\sqrt{2}} q_\alpha \le \delta \le Z_1 + \frac{S}{\sqrt{2}} q_\alpha$

where $S = \sqrt{S_3 / (C-1)\ (R-1)}$

q_α = critical value for the Studentized Range.

The value of q_α is extracted from the indicated table at some value of α (say 0.05) and for the error degrees of freedom (3 in the example). If (4) contains zero (that is, if the left hand term is negative and the right hand term is positive) then the difference Z_1 is not significant. This is performed for the remaining Z's and rankings are achieved on the basis of the relative values of (4). For example,

(5) $B_2 \;\; B_1 \;\; B_4 \;\; B_3$

where the underlines might indicate no significance between differences in B_2 and B_1 but significant differences in B_2 and B_4. We would then conclude that Team 2 is not significantly better than Team 1 (at the 5 percent level of significance) but that the difference in performance betweem Team 2 and Team 4 is significant. This result could be used to indicate that Teams 3 and 4 needed additional training to bring them up to Team 2 and Team 1.

SAFOC DATA COLLECTION

A write-only magnetic tape unit records data directly from the SAFOC computer memory using an I/O channel. The data directly accessible to the tape unit is raw data, not necessarily the data to be processed by analysis or statistical programs. To demonstrate the difference between the two types of data, the following is a partial list of data variables of interest in statistical processing:

- Number of conflicts versus flight density
- Departure queues
- Handoff queues
- Alert queues
- Number of impossible requests
- Departure rate
- Arrival rate
- Alert rates
- Service request rates
- Waiting times in queues

- Communication channel occupancy

- Total fly-through time

- Simulation fly-through time

- Mean service times

None of the above are directly available from the computer memory. The form of most data in computer memory involves the data related to flight plans; the activities at the console and typewriter, such as illuminated or blinking pushbuttons; and the SAFOC status, such as the display modes and content.

The method of obtaining data from the SAFOC is to record events on magnetic tape as they occur. For example, consider the measure of alert waiting time. This is measured by the time between the setting and the resetting of an alert blink bit. When an alert blink bit is set, the type, the time, and the flight number, for which it is being set, are recorded on magnetic tape. When the blinking alert is answered by a controller, the alert blink bit is reset and this event is again recorded on magnetic tape. In order to obtain the alert waiting time, the data reduction program must extract these events from the magnetic tape and compute the difference in time between set and reset of the blink bit for that particular flight.

Alert service queues are also obtained in the data reduction program by extracting the times of set and reset of an alert blink bit. Whenever a blink bit is set, a counter is incremented by one. Whenever a blink bit is reset, the counter is decremented by one. The time history of this counter is a measure of alert service queue length throughout the run.

The Magnetic Tape Synchronizer (MTS) is used to collect SAFOC data by interfacing with one to four Magnetic Tape Units (MTU) and with one of the I/O channels of the SAFOC General Purpose Computer. The MTS provides control of four MTU's through programmed instructions received from the SAFOC computer. The MTS controls data transfers between the computer and the MTU's in both directions; it controls tape positioning, and it supplies status to the computer on itself and any MTU. MTS operations are initiated by programmed instructions received from the computer. Once an operation has been initiated, communication between the computer and the MTS is accomplished by input data requests, output data requests, interrupt requests, and acknowledge signals. This allows transfer of data into and out of memory without impeding program operation.

In order to obtain the SAFOC data, "bugs" are inserted into the operational SAFOC program at the appropriate locations causing data to be recorded on magnetic tape related to particular events; such as:

1. Event occurring (handoff blink, conflict alert, flight hook, etc.)

2. Time event occurred

3. Console initiating event

4. Flight number associated with event (more than one flight number for conflicts).

DATA EXTRACTION

When both the SAFOC history and target generator history tapes are ready for processing, tape data is edited and converted so that the information which will be used for statistical processing is directly available. The handling of this data is performed by the Format and Edit programs. These programs convert the data and store it in appropriate lists. From these lists magnetic tape files are prepared. For the purpose of eliminating data, which may prevent proper statistical processing, a printout of these data lists is also produced. After examining the printout and determining which is "bad data", the Format and Edit programs are rerun, the "bad data" removed, and new magnetic tape files generated.

These files provide the input data for the Analysis and Statistical Programs, which use "packaged" subroutines such as those provided in the Biomed Statistical Package. The elements of such a package are used as subroutines which are "called" as required for the specific statistical processing to be performed. Outputs are histograms and other statistical data such as means, standard deviations, etc.

PHASE I TEST RESULTS

Because a lesser number of controllers were available, the planned testing of four teams was changed to test individual controllers. The results of the controller performance analysis indicate no significant differences in the system effectiveness measures with the results of all operational methods combined. That is, an F test shows that the variation among controllers is not significantly larger than the variation among the test results for the same controller.

A comparison of the incomplete events for each controller was performed. An incomplete event is an alert not answered or a service not completed. An F test indicates that there were no significant differences in the number of incomplete events among the controllers at the 0.1 level of significance.

In addition to the effectiveness comparisons, tests were made to determine if the differences in controller errors per run were significant. The average numbers of controller errors per Phase I test were found to be significant, and the following ranking of the controllers (designated as C, D, L, M, Sk, St, W) was performed on this basis:

Phase I Tests

Ranking: L M W St C Sk

Since controller errors exhibited significant differences among controllers, regression analyses on controller errors versus controller experience, education, and aptitude scores were tried. These analyses did not indicate any significant relationships between controller errors and the other factors.

PHASE II TEST RESULTS

In Phase II, the man/machine system was evaluated using both special purpose scenarios and realistic tactical scenarios supplied by the Army.

Statistical tests indicate that there were no significant differences in controller performance observed in the effectiveness measures used for the tests. Significant differences were observed in the average number of controller errors per run, however, resulting in the following rankings of the controllers:

Phase II Special Purpose Scenarios

Ranking: L C D Sk St W M

Phase II Realistic Scenarios

Ranking: L D W C M Sk St

(not ranked)

EXPERIENCE EFFECTS

C and M were the most experienced controllers while L, W and D were the least experienced. The results indicate that previous air traffic control and radar experience does not necessarily guarantee the best performance. D entered the program more than a year later than all other controllers, and had less time on the system; yet his performance was near the top in terms of controller errors. Thus, it cannot be said in this case that either experience on the system or related air traffic control experience has a great bearing on controller performance.

APTITUDE EFFECTS

Differential Aptitude Tests (DAT) were conducted in the training program. Regression analyses were performed on controller errors versus experience, education and DAT scores. The only significant fit was found for average DAT score and the realistic scenario controller errors. The results indicate that higher aptitude test scores were correlated with better performance.

LEARNING EFFECTS

The tests were run in the following order:

Phase I tests
Phase II tests (special purpose scenarios)
Phase II tests (realistic scenarios)

The data does not indicate any improvement with time attributable to learning. In fact, the data indicates performance degradation with time. The degradation in performance is probably a result of the differences in the scenarios and motivation effects, rather than any negative learning effect.

MOTIVATION EFFECTS

Though motivation effects could not be quantified, it was the opinion of the test conductor that motivation was the primary factor effecting controller performance.

During the tests, an independent subjective evaluation of controller motivation was made by the test conductor:

Phase I Subjective Analysis of Motivation

Ranking: L St M W C Sk

Phase II (Special Purpose Scenarios)

Ranking: L Sk St D C W M

Phase II (Realistic Scenarios)

Ranking: L D C W M

These ranks were compared with the rankings by average number of errors per run and the Hotelling and Pabst's Spearman Rank-Order Correlation Test* applied. Ties were broken based upon the nature of the errors. Controllers with least serious errors were given better ranks.

The rank correlation test is as follows:

Compute Spearman's rank difference correlation coefficient

$$r_s = 1 - \frac{6D}{n(n^2 - 1)}$$

where $D = \sum_{i=1}^{n} d_i^2$

d_i = difference between the rankings for controller i

n = number of controllers

The null hypothesis to be tested is H_0: Ranks are independent versus the alternate hypotheses of positive correlation.

If $D \leq D_\alpha$ where D_α is obtained from tables of the critical lower-tail values of D for Hotelling and Pabst's Spearman Rank-Order Correlation Test for a level of significance α then reject the hypothesis of independence.

The results of this test were:

Phase I: $r_S = 0.886$, $D = 4$, reject H_0 at $\alpha = 0.025$
Phase II: $r_S = 0.75$, $D = 14$, reject H_0 at $\alpha \cong 0.035$
Realistic: $r_S = 1.0$, $D = 0$, reject H_0 at $\alpha = 0.01$

These results indicate that there is no reason to reject the hypotheses of positive correlation between motivation and average errors per run for any of the test situations.

CONCLUSIONS

The results of this evaluation indicate a significant consideration which must be made in the design and testing of any semi-automated system, where a human operator is expected to interface closely with data processing and display equipment.

To attain the level of operator performance necessary to accurately measure system performance, operator motivation must be maintained. In this evaluation, a high frequency of controller errors was attributed to deteriorating motivation, based on the judgment of the test conductor. As the frequency of controller errors rose, the evaluation of system effectiveness was impaired.

Alternatively, the system can be designed in such a way as to reduce the dependency of system effectiveness on the variability of operator performance.

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* Bradley, James V., Distribution-Free Statistical Tests, 1968, Prentice-Hall Inc., Englewood Cliffs, N.J., pp. 91-96.

USE OF DIGITAL COMPUTERS FOR REAL-TIME SIMULATION OF TACTICAL RADAR

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Tactical radar training devices have historically been restricted to the use of multiple servomechanisms to mechanize the radar antenna scan and stabilization equations for use in target and landmass simulation. It is now possible (and, in fact, preferrable) to perform the complete antenna simulation using a small general purpose digital computer and a small amount of special digital hardware. A recent training device has demonstrated the outstanding advantages of this approach. Before discussing this new technique, we should establish the system requirements and discuss some of the previous simulation techniques.

Typical radar training devices are operated as a sub-system within an aircraft training device. The radar simulator will receive information defining the aircraft position (latitude and longitude), the aircraft attitude (pitch, roll, heading, etc.), the gyro attitude, and the radar mode of operation. The radar simulator must then provide accurate positioning of the landmass data (a photographic filmplate), simulate the motion of the antenna,as performed in the actual aircraft system, and provide accurate real-time antenna position information to the target generator (in aircraft reference), the landmass video generation subsystem (in earth reference), and the radar indicator (in gyro reference).

In most tactical radar systems, the antenna is gyro stabilized so that the gyro platform remains horizontal in normal operation. However, it is usually necessary to simulate conditions in which the platform is not horizontal. This means that the antenna position must be known in three separate coordinate systems; aircraft, gyro platform, and earth coordinates. The target generator usually needs antenna position in aircraft coordinates, the antenna positioning signals are usually generated in the gyro platform coordinates, and the landmass information (filmplate) is in the earth coordinates. Thus,it is necessary to perform two coordinate transformations,since the position in gyro platform coordinates is known to follow the prescribed scan pattern.

In general, radar simulators generate and present the radar video at (or near) the actual PRF used in the aircraft. This is especially critical to target/jammer simulation and electronic counter-measures. The PRF rate of typical tactical radars range from 200/sec. to 2000/sec. This means that a new value of antenna position is needed for every PRF and the system must have adequate precision and resolution to destinguish the angular difference of each successive sweep. This is indeed a tough requirement. At the highest PRF (2000/sec.) there is only 500 microsec. between radar pulses to perform computations in the computer.

A brief description of the previous antenna simulation techniques is helpful in understanding the relative advantages and disadvantages of the newer techniques. Servomechanisms offer a physical model approach using servos resolvers, synchros, modulators, demodulators, d. c. restorers, digital shaft encoders, etc. A typical radar simulator using these devices is shown in figure 1. This type of system contains a lot of mechanical moving parts which require precise alignment and much maintenance (motors, tachometers, resolvers, synchros, encoders) and are not overly reliable. The electrical problems are noise generation, complex wiring, and difficulty of changing configuration or parameters for different modes of operation. The modulators demodulators, and d. c. restorers add some error and require careful adjustment. The overall complexity of this system makes it generally difficult to adjust and maintain.

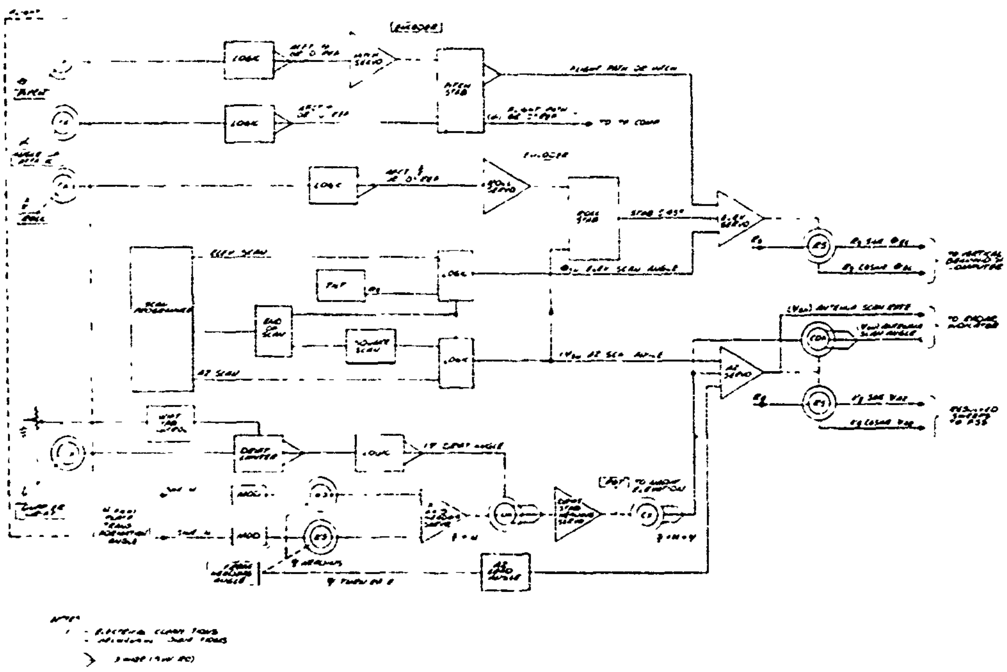

Figure 1. A Typical Simulation using Servomechanisms

Utilizing a general purpose mini-computer, a much better radar simulator can be built improving on every aspect both technically and economically. The basic system design is shown in figure 2, and the computer configuration is shown in figure 3. The most important techniques are the multilevel priority interrupt system, the Sine/Cosine function generator, the MDAC (Multiplying Digital to Analog Converter), and the software interpolation techniques.

The basic approach to the problem is based on the multilevel priority interrupt system as illustrated in figure 4. The highest priority is used for PRF rate computations (up to 2000/sec.), the next level is used to compute the coordinate transformations and all other computations not requiring PRF

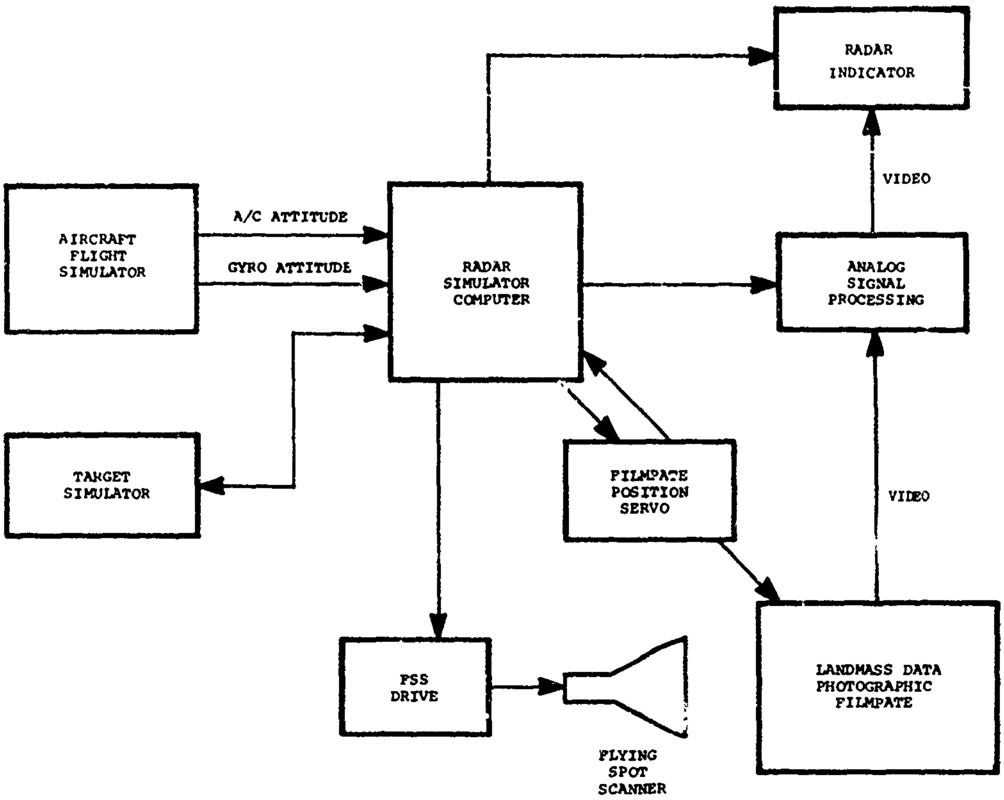

Figure 2. Simplified Block Diagram

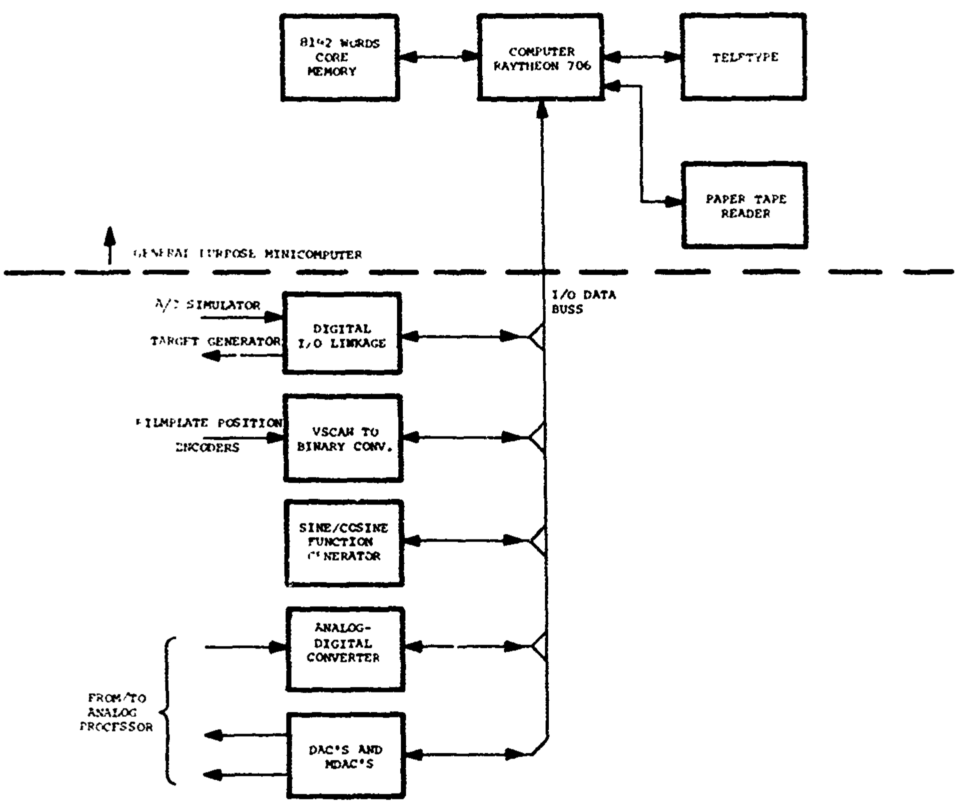

Figure 3. Computer Configuration

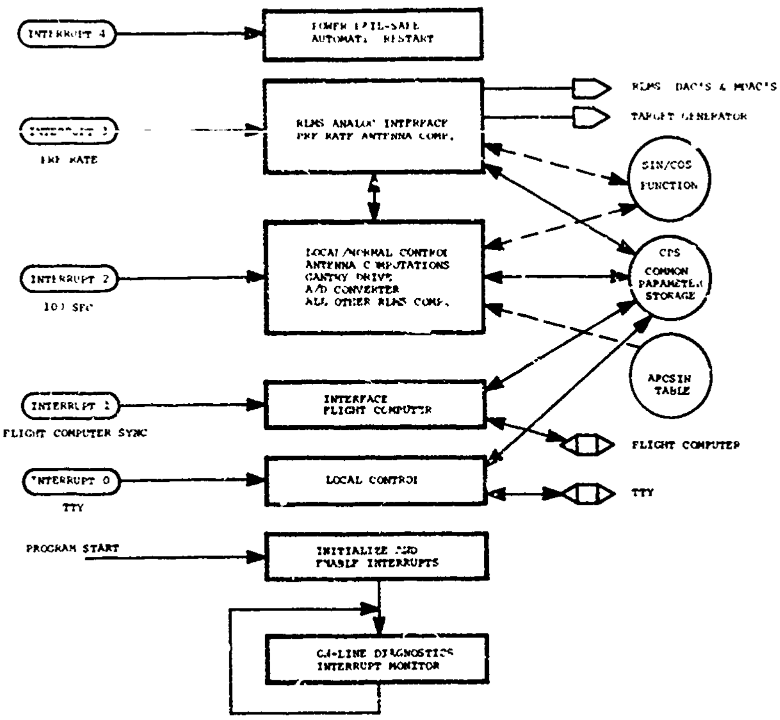

Figure 4. Software Architecture

rate update at a fixed rate of 100/sec. A lower level is used for interface between the radar simulator and the aircraft simulator at a rate of 20 times per second to transfer aircraft and gyro attitude. The lowest level is used for interface with the teletype to allow real-time operator interaction with the simulator. The "mainloop" is used for diagnostics and other nonreal-time tasks. This use of the priority interrupts reduces the computer overhead and provides an efficient and convenient way of partitioning the computer time.

At the maximum pulse rate of 2000/sec., it is not possible to perform all the necessary calculation. Thus, the highest rate interrupt (2000/sec) is used primarily for interpolation of the values computed at the 100/sec. rate and for resolving the angles into X and Y components for the radar scanner and the radar indicator. A simple linear interpolation is adequate to follow the antenna motion. The very complex coordinate transformation equations are solved at 100/sec. rate.

Sine and Cosine functions are used many times for solving the coordinate transformations and for resolving angle into X, Y components. A software subroutine to calculate these functions would require far too much time. Therefore, a special hardware Sine/Cosine function generator is used to give very fast computation of Sine and Cosine. Figure 5 shows a simple block diagram of the Sine/Cosine function generator. An interpolation scheme is used to determine the values of Sine from 0 to 90 degrees. The Read-Only-Memory provides 256 full words (16 bits) and 256 half words (8 bits). The address selects one full word and one half word which, when added together, will give the value for that angle. The quadrants and

the Cosine function are then obtained from the Read-Only-Memory by complementing either the address or the answer or both. This technique provides a resolution of .02 degrees with an accuracy of ±.02%. The total computer time required for any Sine or Cosine is only 2 microseconds (a single instruction).

The MDAC (Multiplying Digital to Analog Converter) provides the means for the digital computer to control the amplitude of various analog amplifier waveforms. The MDAC difers from a normal digital to analog converter only in that the reference voltage need not be constant. The digital value from the computer is in effect, multiplied by the analog voltage. This is primarily used for driving the radar scanner and the indicator. Analog signals as high as 100 KHZ can be controlled by the MDAC with an accuracy of .05%.

Using these techniques, this system has clearly shown that the use of a digital computer offers many advantages. The system is very versatile. It can more easily be modified to respond to various modes of operation or to simulate changes in the radar system. The computer can be used to perform many other tasks such as diagnostics, and automatic checkout or monitoring of parameters (power supplies, line voltages, temperature, etc.). The computer almost completely eliminates moving parts, thereby, greatly increasing reliability and decreasing maintenance. The computer provides much greater accuracy and resolution and greatly reduces the amount of adjustments required to calibrate the system. The list of advantages is limited only by the imagination. Further modifications can be easily accomodated in the remaining 30% of the computer time and core memory.

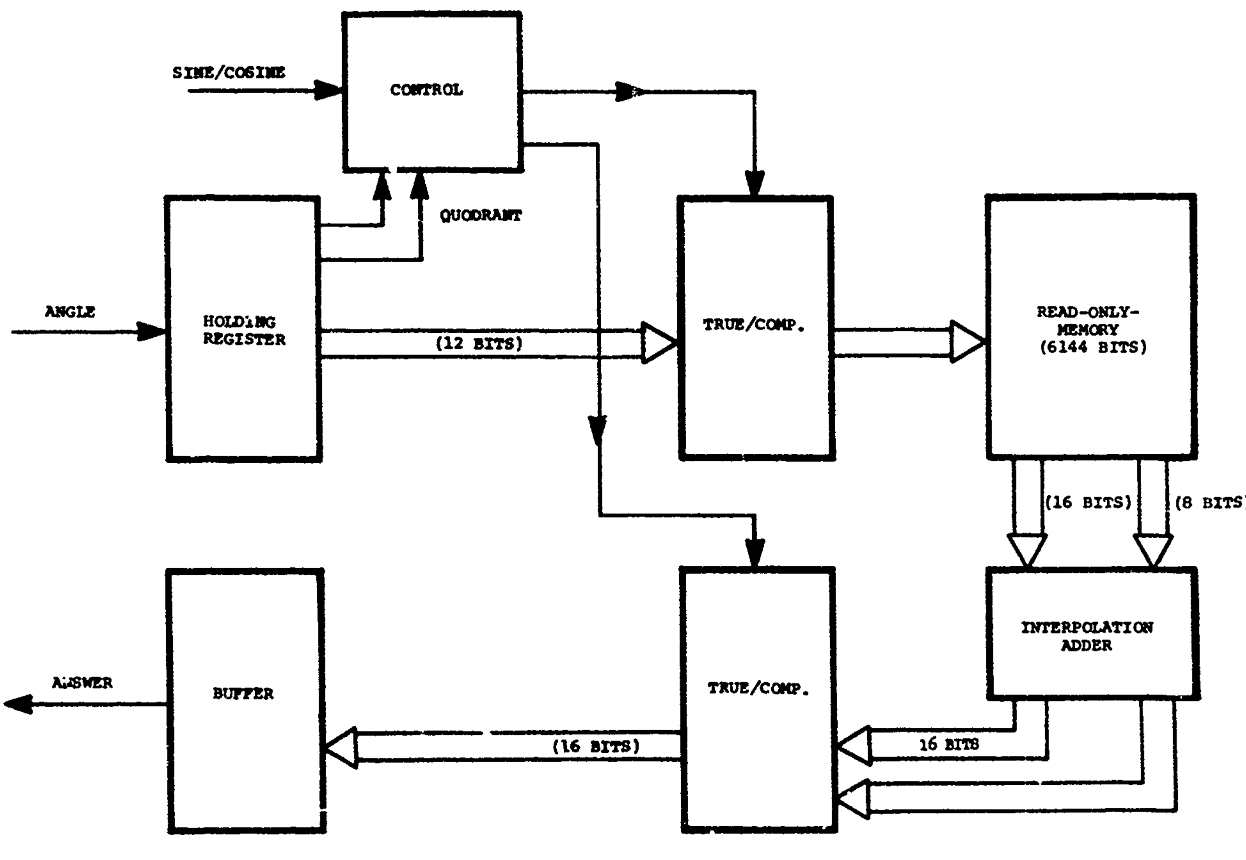

Figure 5. Sine/Cosine Function Generator Block Diagram

DIGITAL RADAR LANDMASS SIMULATION

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What is landmass radar? Landmass radar may be defined as any radar which scans the ground for the purpose of navigation and or target identification. Landmass radar may be either airborne or shipboard (surface).

The airborne landmass radar, which is used only for navigation purposes, provides the aircraft navigator with information about the terrain and reflectivity of the scanned area of a more or less gross nature. For example, the outlines of cities, hydrographic features, ridge lines and shadows caused by intervening peaks are observed and by comparison to the maps and charts, the flight of the aircraft is navigated.

A much more precise-type radar is that which is used for either terrain avoidance navigation and/or target identification. When on a terrain avoidance-type mission, flight close to the deck, the aircraft navigator is very much concerned with the exact location of the underlying hills and valleys, as well as the accurate determination of their elevation. The use of the aircraft's landmass radar for the purpose of target identification requires a high degree of resolution for the equipment and considerable operator skill since this mode of operation would normally require the acquisition of a small target (e.g., a building) at considerable distance.

The shipboard (surface) landmass radar is simpler than the airborne landmass radar in that there is one less degree of freedom; it is located at a fixed altitude. Like the airborne systems the surface landmass radars are used for navigation and/or target identification. These radars generally scan the shoreline at both great distance and within a harbor. Navigation within a harbor usually means radar determination of distance down to meters. This type radar is also used to guide fire control on the shoreline targets.

Radar Landmass Simulation: Radar landmass simulation is the simulation of the radar, which scans the ground, for the purpose of navigation and/or target identification. The device, which performs this function, is called a radar landmass simulator RLMS. Such devices are used to train navigators, nav-bomb operators, and bombardiers. These RLMS devices are also used for pre-mission briefings of operational flight crews.

To date all such training devices have been of an analog type. The most successful, and that which is currently used, is the transparency radar landmass simulator.

In a transparency-type RLMS, the simulated radar display data is stored on a photographic transparency, which is read by a flying spot scanner. Two basic types of information are stored on these transparencies. They are terrain height and reflectance. Both types of data are coded as shades of "grey." This photo-optic information is then converted by a photomultiplier tube into an electrical signal.

The signals generated by the photomultiplier tubes are processed by analog computation hardware. This computation uses the terrain height and reflectance data from the transparency, as well as aircraft flight and radar display parameters to solve the radar equation. The resultant information is then sent to the simulated radar display scope.

There are two major variations on this transparency approach to the RLMS problem. They are: (1) A "factor transparency" system where there are two photographic plates, one for terrain height and one for reflectance; and (2) a color system where each type of information is stored as a separate color. The latter system must provide the additional optics to separate the colors.

For both types of transparency systems there exists a set of common problems. These are: (1) High initial cost of the photographic plates; (2) high cost of duplicate plates for additional trainer; (3) the inability to update existing plates (requires a re-manufacture of plates); (4) the opto-mechanical complexities of positioning and scanning the transparencies; (5) the need for a separate transparency and scanning system for each cockpit where multiple station trainers are required; (6) with the approximate 5,000,000:1 scale, missions requiring high resolution (such as terrain avoidance) are not possible. To solve these problems and to provide better training, digital radar landmass simulators, DRLMS, are being proposed.

Possible Digital Radar Landmass Simulation: There are several possible different types of digital radar landmass simulators, DRLMS. The major differentiating factor is the form in which the radar data is represented.

A straightforward method is to divide the map into squares, and for each square store a height value and reflectance. The resolution of this type of digital system is defined by the size of these squares. This is somewhat equivalent to the resolution of the data on the transparencies.

The resolution of the transparencies is approximately 250 feet. For an equivalent resolution using the straightforward method above, an area of 1500 x 1500 miles would require 10^9 words of data. A word consists of the necessary number of bits to represent the height and reflectance of each square.

The data required for a single ppi scan (135 degree sector 200 mile range) using the 250 foot resolution is approximately 2×10^6 words.

It can be seen from the above that the digital systems are faced with several major problems with respect to the radar data. These are: (1) Obtaining the required data in digital form; (2) storing this extremely large amount of data for real-time use; and (3) transferring this digital data from the mass storage devices to the processor in the available time.

In general, the solution to the data storage and transfer problem is found by trading an increase in data processing for a decrease in the amount of data, i.e., the use of some data compression scheme. In the larger sense this tradeoff is much more complex, involving many factors such as the training requirement, the resolution, inclusion or omission of effects, the amount and sophistication of the hardware, as well as price.

Of the various data compression schemes, two in particular are mentioned here. The first is a compression scheme where the area of interest is sectioned by a grid, (a coordinate system). This grid has a larger spacing than the fundamental resolution element. Associated with grid points are coefficients, which are then used, to reconstruct the terrain height at any particular resolution element by the use of a polynomial approximation. These polynomic approximation techniques are usually applied to the terrain height information since it is assumed that the terrain height function is well behaved.

The second major data compression scheme uses a planar surface fit, approximation of the three-dimensional surface by a set of flat plane surfaces. This, then, says the radar data can be defined graphically as a set of vertices and edges. The accuracy of the fit would determine the number of edges required.

The digital approach to the radar landmass simulation problem provides the capability of updating the data base by nothing more difficult than a program reading the update punch cards. It allows for multi-training station access to a single data storage. It eliminates optomechanical complexities since there are no servos or optical scanners, and allows for inexpensive duplication of the simulation data base. The predominant disadvantages of the analog radar landmass simulators are overcome by the DRLMS.

The Feasibility of DRLMS: In the past two or three years there has been much interest in digital radar landmass simulation. This interest has been found in both industry and DoD.

There has been much effort, particularly in industry, to demonstrate that the digital approach to radar landmass simulation is feasible, practical, and the correct direction in which to steer the wheels of progress. An analysis of each of these feasibility demonstrations reveals the rather common tact of looking at one particular portion of the entire DRLMS problem. Each of these demonstrations has generated a radar display of sorts, for obvious sales purposes, without the overall analysis of the total-system problem. The actual system requirements, based on the type of training required, have not been specified.

It might be well to consider a different approach to the simulation of each of the various types of landmass radar mentioned above.

Much of the industrial interest in DRLMS has been generated by the Air Force procurement of an Undergraduate Navigation Training System, UNTS. This was an immense undertaking in that the system was initially specified as an all digital trainer with 46 trainee stations, each with free flight capabilities. The data base was to be at least half of the United States, at a resolution of 250 feet, expandable to 150 feet. There was much controversy along with protests, over this procurement, with bids ranging from 16 to 42 million dollars. The successful bidder was Honeywell Marine Systems Division, West Covina, California, with initial delivery scheduled for August 1973.

A concurrent project along with UNTS is that of providing the digital data. This undertaking is being carried out by the U.S. Army Topographic Command, and the U.S. Air Force Aeronautical Chart and Information Center.

The results of all these feasibility studies have in general shown that Digital Radar Landmass Simulation is possible, but not trivial or simple. There are many unknowns, most of which are in the realm of providing a quantitative as well as qualitative performance specification for each of the various requirements.

NAVTRADEVCEN's Research in DRLMS: With the interest generated in industry by the Air Force UNTS, NAVTRADEVCEN's role in the RLMS field has changed, from providing the initiative for DRLMS research, to that of providing the Navy with a comprehensive performance specification for the Digital Radar Landmass Simulation of each type of landmass radar.

The preparation of such a performance specification involves works in three particular areas. These are: (1) Determination of the training requirements, the degree of required realism, and how the training requirements relate to the quantitative parameters of such simulators; (2) to develop objective as well as subjective evaluation techniques to determine what constitutes a "good" simulation; (3) to evaluate various simulation schemes in comparison to a baseline system developed in-house via non-real time simulation studies. An example of such a comparison is shown in figure 1. Figure 1a shows the simulated radar display of the Scranton-Wilkes Barre, Pa. area, using the NAVTRADEVCEN base-line system (no data compression). Figure 1b shows the same area; however, the terrain data was compressed and decompressed using LaGrange Polynomials. The effects of the data compression are shown as a decrease in detail and a general smoothing of the terrain. But the major navigation features are still observed. The question remains, what is required for adequate training?

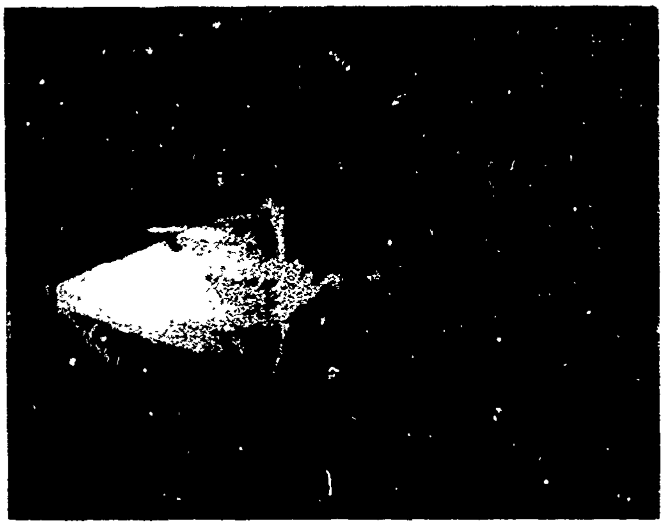

Figure 1a. Scranton-Wilkes Barre, Pa.
NTDC Base-Line System
(No Data Compression-7,000 Feet)

Figure 1b. Scranton-Wilkes Barre, Pa.
(LaGrange Polynomial Data
Compression-7,000 Feet)

The NAVTRADEVCEN base-line system is configured in such a manner that a non-real-time software simulation of a DRLMS is performed on a general-purpose Sigma 7 computer; and the results, the simulated radar displays, are then displayed on a CRT in real-time via special-purpose interface hardware. This is equivalent to observing preflown missions. This special-purpose interface hardware and display, constructed in-house, is shown in figure 2. The data base used for these studies consists of a 60 x 270-mile area of northern Pennsylvania (i.e., the Warren, Williamsport, Scranton USGS maps). The terrain data for this area was obtained from U.S. Army Topographic Command. The reflectance data for the same area was obtained by digitizing 250,000 U.S. Geological Survey maps. The base-line system utilizes no data compression techniques, or other computational shortcuts so that the displays generated will be best possible for the available data. The programing of both the base-line system and the software simulation of a DRLMS is written in Fortran to provide a high degree of flexibility for experimentation.

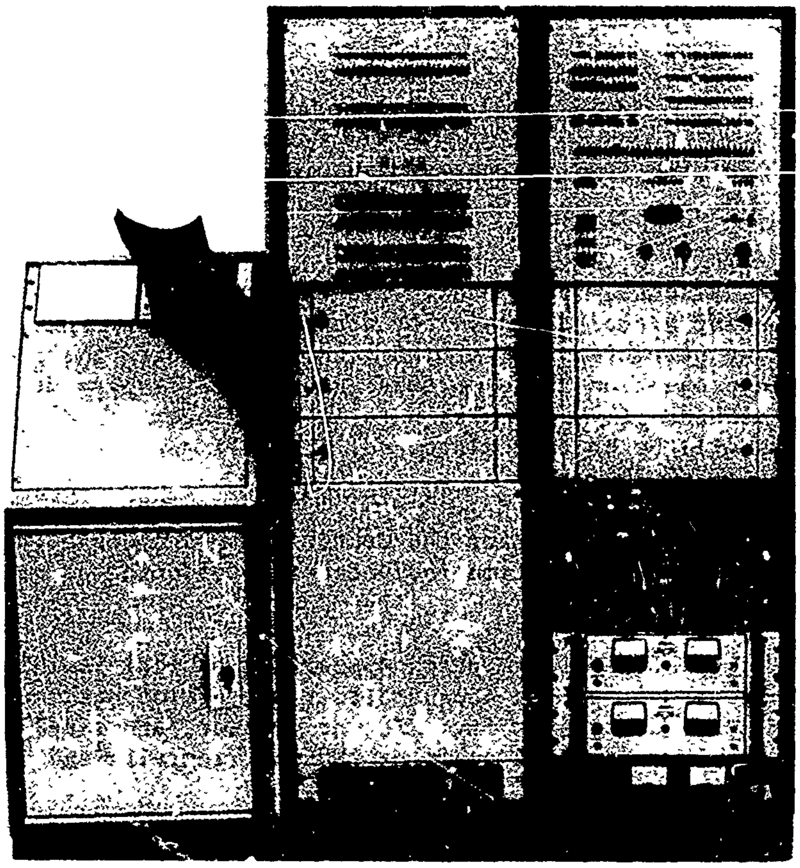

Figure 2. RLMS Interface and Display Hardware

CONCLUSIONS

The digital approach to radar landmass simulation is the approach of the present and the future. Digital radar landmass simulators will have the flexibility to provide easy updates of the data base and simpler maintenance. DRLMS also provides for the use of a single data base by many independent trainee stations. The technological advances of the past few years have made digital radar landmass simulators possible, but there is much work to be done before they will be fleet operational.

WIDE-ANGLE PROJECTION TELEVISION

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INTRODUCTION

This paper will discuss, in general, wide-angle projection television as a tool for producing visual displays for training devices. It will describe the defining parameters and provide two solutions to the problem of using wide-angle projection TV for providing a visual display of the real world - both methods of which exist here at the Center. Two other potential solutions will be briefly discussed. Typical applications will be offered.

A feasibility study performed for the Center(1) on the use of wide-angle television for visual simulation indicated the following as requirements for the display:

1. Observer should see an image which appears at optical infinity, and
2. Field of View (FOV) must be adequate to take care of head motion, and
3. Brightness must be at least five FTL, or greater, and finally
4. The image should subtend an angle of 180° horizontally and 90° vertically.

The study went on to say that it is known that the eyes are accommodated at infinity, when seeing objects at 100 ft, or more, and a simulated display should present an image at infinity.

A second, more recent study(2), agreed that a scene focused at infinity, was one focused at 50 feet. The study further found that an image at 10 feet distance cannot be di tinguished from one at infinity if:

1. It is displayed on a screen of sufficiently large angle, and
2. if there are not connecting structures between the observer and the screen to give distant cues.

The second study verifies that the requirements for a viewing system, for simulation of the real world, be at least 10 feet distance and that the highlight brightness be five Foot Candle Lambert (FTL) or more. With these definitions, the requirements have been set forth on using television for simulation of the real world in a visual display.

Two methods for generating a visual display which allows the simulated scene to appear distant are:

1. through the use of a CRT projector, forming an image on a diffusing screen forming a portion of a sphere with a radius of feet or more, or
2. a smaller image can be made to appear at infinity by interposing a lens between the viewer and the screen. The focal length of this lens should be equal to the distance between the screen and the lens.

   This system, of course, is the virtual image. There is some disagreement with the findings of these studies. It has been suggested that 20 feet should be the minimum distance from observer to image. Also, with the virtual image, large liquid lenses are now available up to 100 inches - so the confinements to small images no longer exist.

SYSTEM

A typical wide-angle projection system includes all the subsystems shown:

$\boxed{\text{Image}}$ - $\boxed{\text{Optics}}$ - $\boxed{\text{Sensor}}$ - $\boxed{\text{Processor}}$ - $\boxed{\text{Projector}}$ - $\boxed{\text{Optics}}$ - $\boxed{\text{Display}}$

The result of the system is the display, which is partially defined with a minimum of four parameters:

1. Brightness or the level of luminance reaching the eyes.
2. Resolution or TV limiting response lines or optical line pairs.
3. Contrast or the ratio of the object to surrounding brightness
4. Visual Acuity or the resolution expressed in terms of the human response characteristics - usually minutes of arc. These parameters define a monochrome system. Additional characteristics would be required to define a color display.

SOLUTION

CRT PROJECTION. The first solution to a wide-angle TV presentation is to parallel three separate systems. Each projector displays a segment of the total display. The existing system uses three 5AZP4 projection tubes with the following characteristics:

Second Anode Voltage	40 Kv
Focus, or G3	8 Kv
Spot Size	7.8 mils
Resolution	750 lines
Brightness	1400 FTL

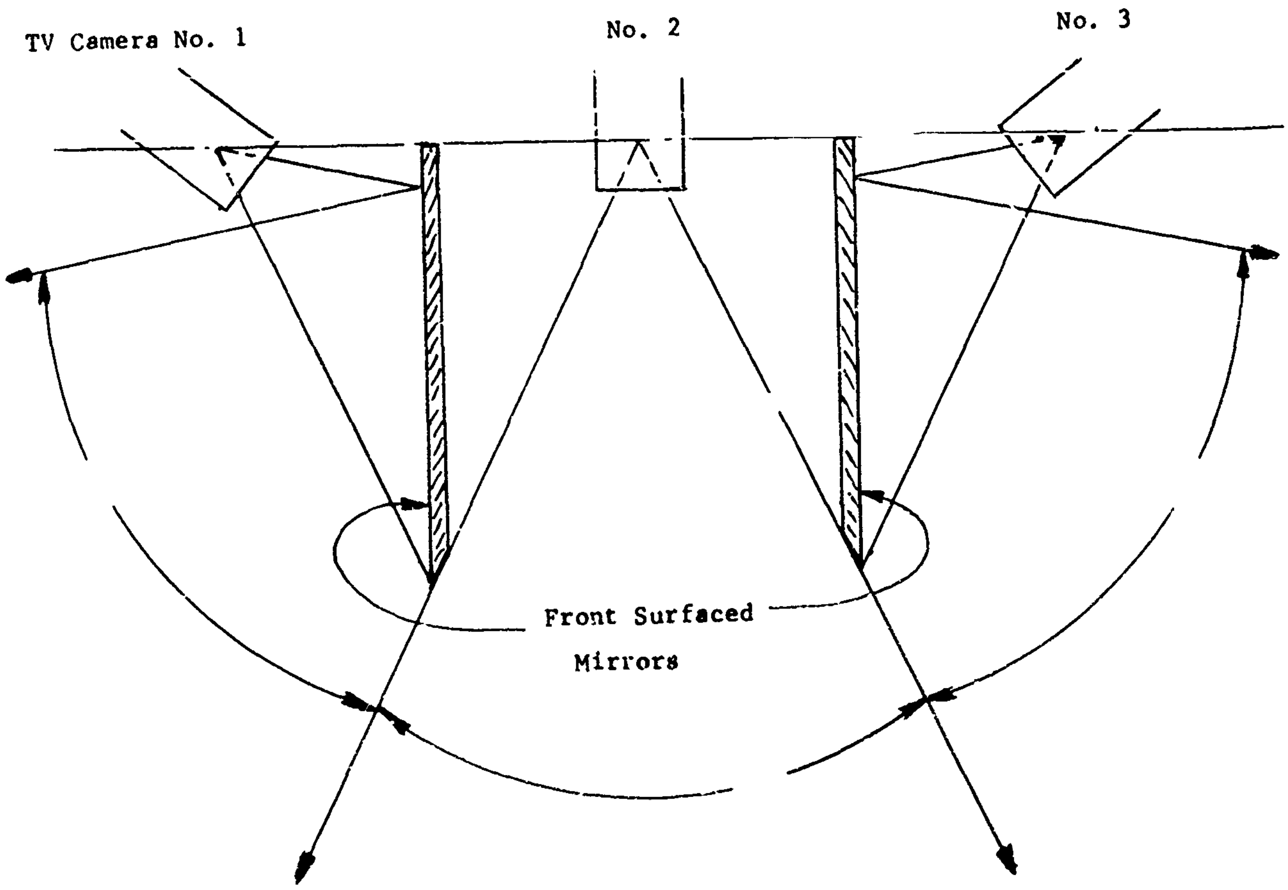
at 250 Beam Current
for 9.5 sq. in. faceplate

The three projectors are mounted 9 inches above the optical center of a 10-foot radius spherical screen at an angle of 21°. Each projector provides a 53° x 53° FOV. This provides a displayed area of approximately 300 square feet. System measurements of the visual display utilizing a screen with a gain of 2.3 are as follows, per channel:

Brightness, approx.	1.0 FTL
Resolution, Horizontal	450 TV lines
Vertical	500 TV lines
Visual Acuity	14.2'/line pair
Scan Rate	875 lines per frame
Video Bandwidth	20 mhz $\pm$ 3db

A novel feature of this total system, as currently used, is the pickup camera probe(3). Designed after Douglas(4) work, the optics is a reflective three-channel system using f/1.5 mm Kinoptik Apochromat lenses as shown in figure 1. Each camera images a 53° FOV.

The front surfaced mirrors image 53° FOV's. A comparison of this new and the replaced lens system, on a relative performance basis, indicates: a 3 V differential in target voltage produced a 31:1 change in P-P video on the f/1.5 system, as compared to a 6 V differential for a 5:1 change.



Vertical FOV = 53°

Figure 1. Ray Trace View - New Optical Probe

The replaced lens was limited to 65 V P-P video, compared to over 180V on the commercial system (figures 2, 3). The mirror channels reduced the video levels by the predicted 50%. The disadvantages of the CRT projection system are:

1. The seams may be objectionable. The introduction of the transition lines between segments of the display may detract from a trainees decision, or provide visual cues not available in the non-simulated vehicle.

2. The brightness is low. This level (1 FTC) is the minimum required to produce the gray scale.

Light Valve Projector. The second solution, in the use of wide-angle television, to produce a visual display is the light valve. In the Center's application the Eidophor will be referenced, because it is used in an in-house task, although other light valve systems will be mentioned later as potentially excellent solutions. The system operates with the use of a control layer. The elementary control layer principle is shown in figure 4. A 0.1mm thick layer of viscous oil, almost totally nonconductive, is spread on a metallized mirror. Electro-static charges cause deformation of the oil layer allowing light to pass through the Schlierren lens. If the electron spot on the oil layer is of such a size that the scanned lines are sufficiently wide to touch

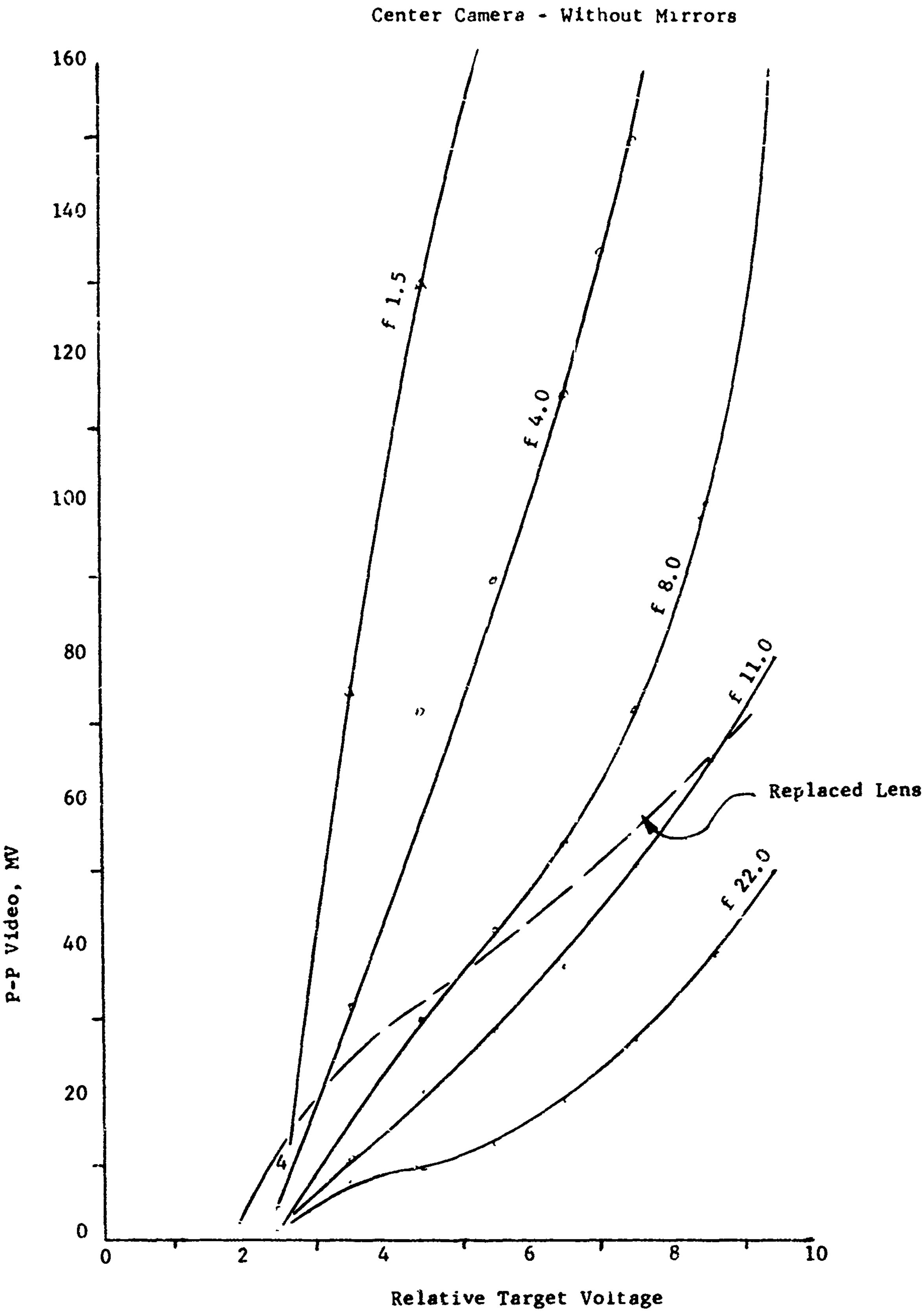


Figure 2. Relative Video Output

Outside Camera - With Mirror

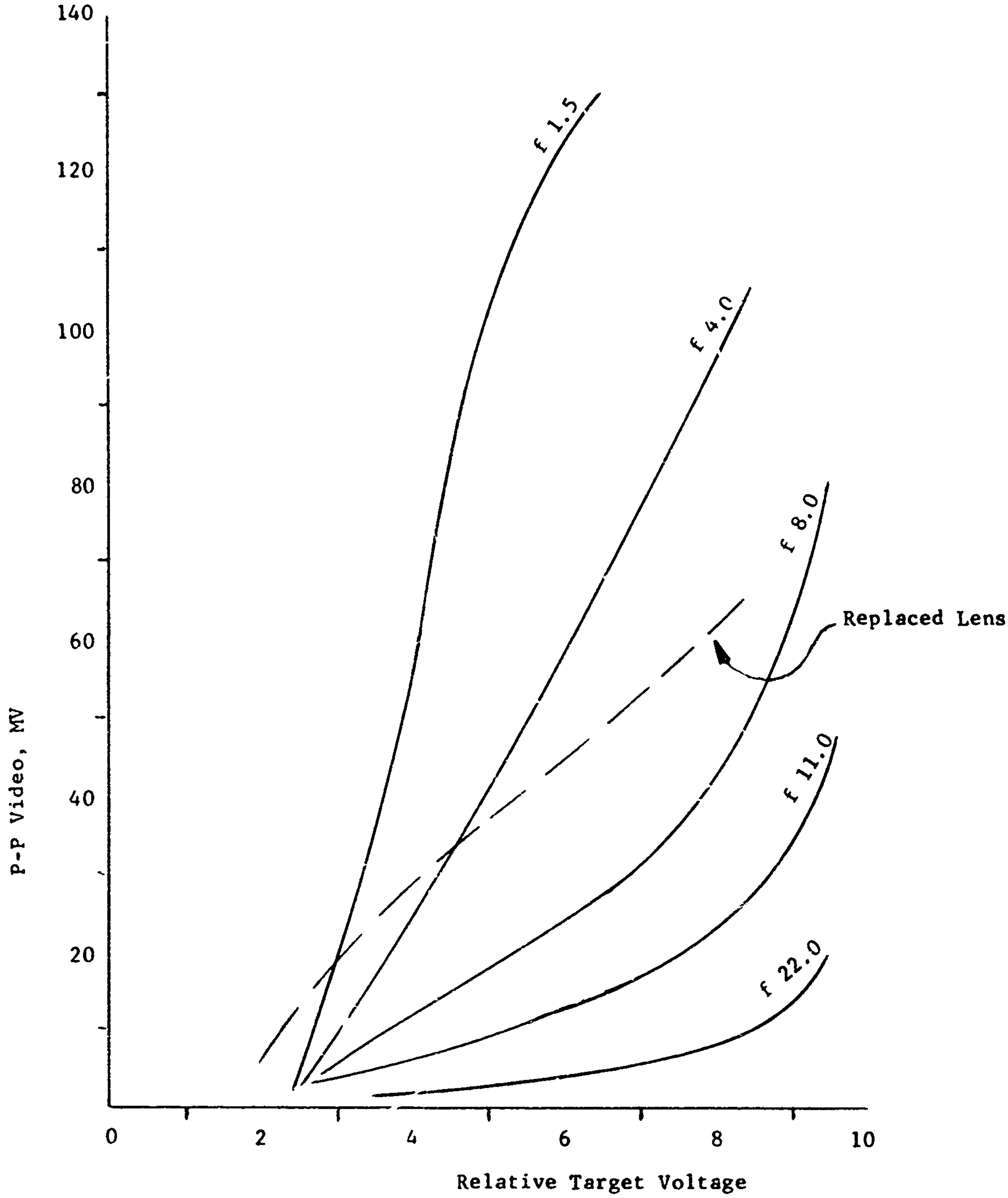


Figure 3. Relative Video Output

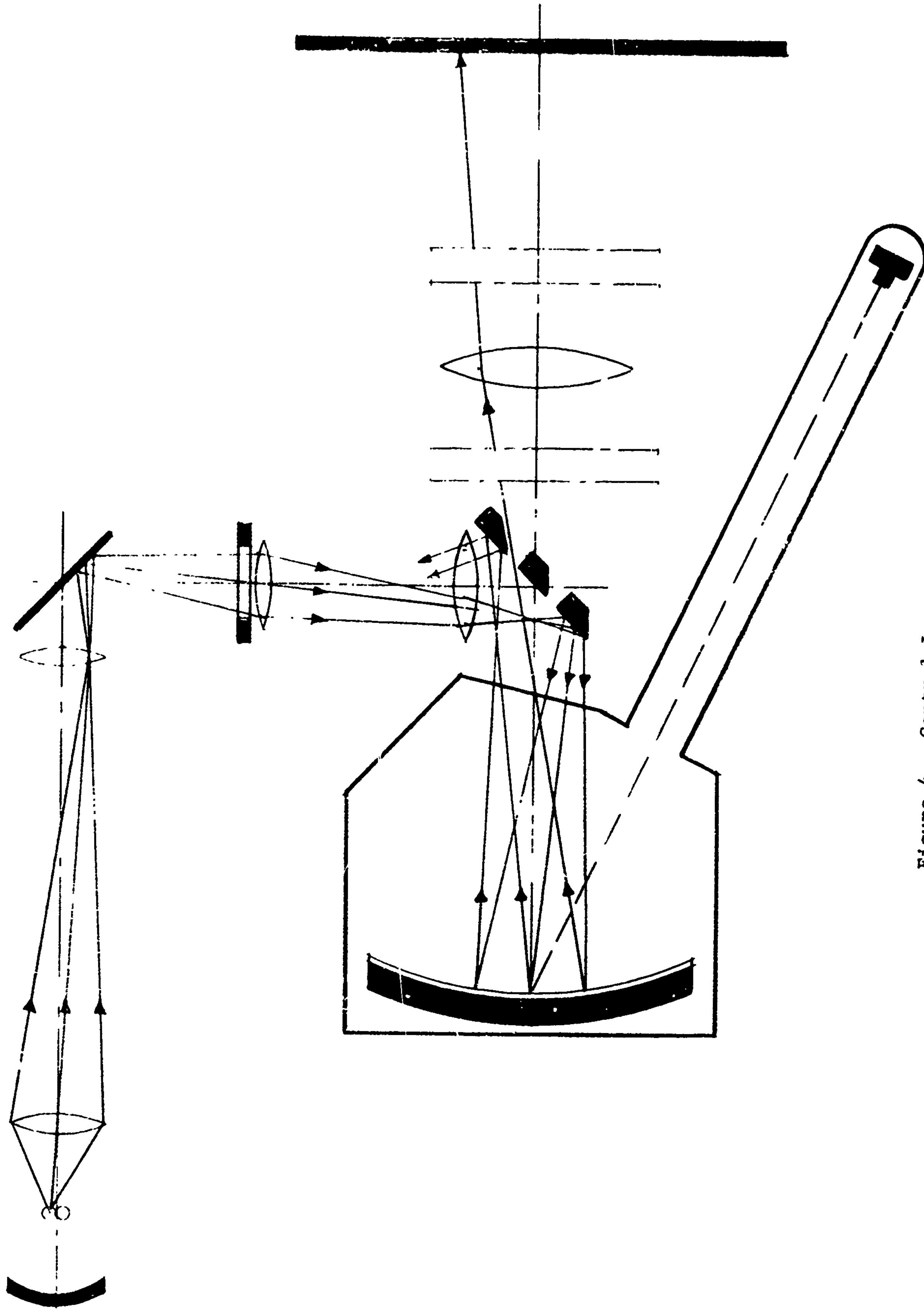


Figure 4. Control Layer

along their length, the charge will be distributed evenly over the whole layer. This layer is, therefore, subjected to a constant pressure over the entire scanning area and thus remains smooth. In this case the screen remains dark. If the electron spot is reduced in size so that adjacent lines no longer touch, there is a charge-free space between the lines. As a result, the pressure distribution assumes a pattern of linear structure that produces a deformation of the oil surface, and thus the reflected off angle light passes through t' e ba.'s. Variances are obtained by changing the size of the electron spot - with the video information. The EP-4 unit in the lab is defined as follows:

Light Source, Xenon Lamp	1600 W
Light Output, Open gate	2025 Lumens
Illumination Uniformity	68%
Contrast Ratio	166:1

The in-house light valve has been subjected to a visual test to determine its capability in limiting resolution. Bypassing the video amplifier, 1600 horizontal TV lines have been projected. With the existing video amplifier and a wide band camera (32 mhz) 1100 TV lines were displayed.

Because the system was obtained to develop and study a high brightness wide-angle display, it was necessary to obtain custom optics to perform the task. A set of matching lenses, camera and projection were designed, constructed and tested to match the system by an outside optical contractor. The matched lens pair are anamorphic and provide a 60° vertical by 160° horizontal FOV.

The camera lens is 1/5.66th scale of the other. The characteristics of the lenses are:

Relative aperature, variable		f/5.6 nominal	
		H	V
Effective focal length, camera		4.4	8.2 mm
	projection	24.5	46.2
Back focal length, camera		71.5 mm	
	projection	377 mm	
Relative Illumination		65%	100%
Resolution, f/8	camera	200 l/mm	
	projection	28.5 l/mm	

The camera lens is variable in focus. The lens were measured with a 200 KC target and an aperature of f/5.6 and found to provide a depth of field of 6" + 18'. Geometric distortion in the camera lens, caused by the anamorphic elements,(different magnification in the horizontal and vertical planes) strictly cancels in the projection lens. The Physical Science Laboratories[5] measurements are shown in figure 5. The light valve again was mounted with its lens 9 inches above the optical center at an angle of 21° in a 10-foot radius spherical screen. Measurements taken on the assembled system indicate —

Highlight Brightness (SG = 2.5)	10 FTL
Resolution, limiated by input system	H 400 lines
	V 700 lines
Visual Acuity	27'/line pair

Improved cameras are on order which will provide 1500 lines horizontal resolution.

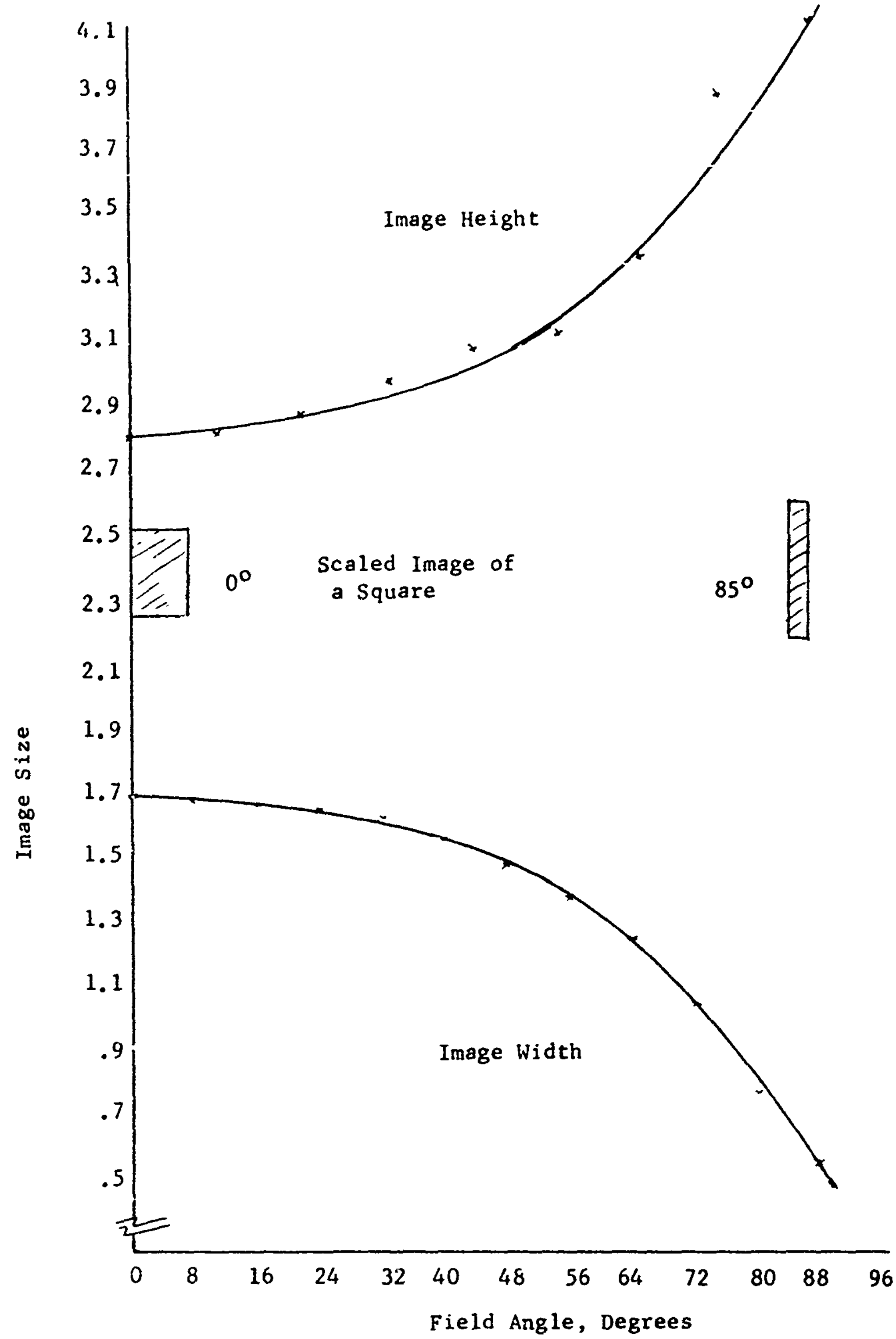


Figure 5. Image Size vs Projection Field Angle

The 400 lines horizontal resolution are highly deficient in providing a display for effective training. In fact, the projected image is barely legible. In excess of 1000 TV lines are required to be comparable to the three CRT projector system. One thousand five hundred TV lines would be required.

Summarizing the advantages of the system are:

a. Highlight output
b. High potential resolution
c. High contrast ratio.

With the improved cameras, the light valve system will be equal to the CRT system in visual acuity, with highlight brightness increasing by a factor of ten, and vertical resolution improved by 40%.

The criterion of acceptable illumination vs resolution, or visual acuity, has been studied many times in the past. The studies have generally concluded that improvements in tasks result quite rapidly from one FC to 10 FC illumination. The rate of increase, however, reduces sharply above this value. The level of 10 FTL should be acceptable in the developed system.

Other Light Valve Systems. Two other light valve systems are in development, or production, which offer real solutions to wide-angle displays, and should be mentioned here for comparison to the in-house system.

a. The color TV projector, a light valve by General Electric uses a single gun to write three color pictures simultaneously on the same control layer in the form of diffraction gratings. Where the pitch of the diffraction grating determines the dispersion of the spectra, while the amplitude determines the intensity. The resulting optical spectra are filtered at the output bar plane to give the desired colors. The performance of the system currently in-house is defined as follows:

Brightness, 650 W Xenon	
Intensity (10 FTL on SG-2.5 @ 7' x 10' screen)	300 Lumens
Resolution	600 lines
Contrast Ratio	75:1
Screen Width	2'-20'

The reliability of the system is reported to be 1500 hours, with further development expected, to provide operating life time of greater than 5000 hours, without replacement of the sealed unit. This light valve has been tested satisfactorily at the maximum motion of 3.7g on the American Airlines 707 Flight Simulator at Dallas.

The projector has recently been redesigned to improve the optical efficiency. It is now claimed that a 500W lamp is equivalent to a 2Kw in another system. With 27 optical surfaces, improvements have been made in the dichroic transmission of the surfaces. The advantages of the system are: the relative portability with the remote projection head; full color, and low power requirements. Also, no registration problems exist with a single electron gun. The sealed unit eliminates heater contamination from the control layer. The disadvantage of the system is the replacement cost of the sealed unit - reported at $10,000.

b. The third light valve, which should be mentioned, reported at the SID Conference in March 1971, is the Japanese version of a sealed light valve, which again is unique in the method of intensity modulation of the target. The target consists of a transparent resistive membrane with a mesh electrode and deformable fluid. An IO glass target is used as the resistive membrane. To this, a vacuum deposted Al film is applied. A thin silicon oil film is applied to the surface of the membrane. An electron beam scans the other side of the

target and sets up an electric charge causing deformation of the oil film. With this system, the oil film is not scanned directly, so replenishment or a vacuum pump are not required.

The results of this system, obtained to date:

Light intensity	
500W Xenon	100 Lumens
Resolution	300 lines
Contrast Ratio	15-25:1

Further improvements in brightness and resolution remain to be achieved.

APPLICATIONS

Wide-angle projection television can be used, where a large FOV is required, in particular training situations. To mention, and discuss several of these:

a. Experimental Destroyer Docking Simulator. The Simulator located at the Center utilizes the three CRT projectors, described earlier. A computer-controlled gantry probes a 100:1, 3D model, with the optical probe mentioned earlier, to provide the video for three channels. A trainee viewing the display provides engine and rudder orders to control the vessel. The verbal orders are fed to the computer, where the recomputed, math model equations provide the signals to update and control the gantry's azimuth and heading. The visual system was evaluated[8] subjectively by Naval officers assigned to destroyer duty. The system, generally rated favorable, was critized for resolution of detail of the visual system. The relatively poor resolving power and highlight brightness were the causes.

b. Carrier Landing Flight Trainer. Device 2H87 was designed with a virtual image 240^{o} FOV television display.

c. OOD Trainer[9]. This simulator, the first to use the light valve wide-angle anamorphic lens is a research tool to study visual systems, in particular, wide-angle projection television and its application for underway officer of the deck trainee and, in particular, a replenishment at sea operation, using only visual references. This operation involves approaching and keeping alongside another ship for a long time and under extremely adverse weather conditions. Range data varies from 1000 yards, at the start of the problem, to about 30 yards at the conclusion.

The use of the wide-angle anamorphic lenses provided an interesting problem. With the high geometric distortion, an image generated in the pickup lens must be displayed in exactly the same position in the field of view of the projection lens, or the distortion introduced in the image will not rigorously cancel. This dictated that no electronic changes in the image could be made, such as ranging or changes in azimuth or elevation. As such, the changes must be performed mechanically. The 3D model and camera will be servo driven.

CONCLUSIONS

In conclusion, the current projection system may be summarized as follows:

	Resolution
Camera Lens	2000 TV lines
Pickup Tube	1500 " "
Video Amp (40 mhz)	1500 " "
Light Valve Projector	1600 " "
Projection Lens	1700 " "
System Resolution	730 " "
With a Highlight Brightness	10 FTL
on a Field of View of	$60^{\circ} \times 160^{\circ}$

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COMPUTERIZED OPERATIONAL TRAINING FOR AEROSPACE SYSTEMS: AUTOMATED PROGRAMED INSTRUCTION (API)

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This paper concerns the Automated Programmed Instruction project developed and produced for the United States Air Force Aerospace Defense Command by the System Development Corporation. In 1965, the System Development Corporation commenced a project to determine the feasibility of implementing the concept of computer-assisted instruction into an operational air defense computer. This early research was conducted on the BUIC Air Defense System computer. BUIC, an acronym for Backup Intercept Control System, was then in the BUIC II phase. This early SDC research culminated in a determination that the concept of computer-assisted instruction could effectively be implemented into an operational system. In essence, the determination that individualized training based on accepted concepts of computer-assisted instruction could be accomplished, using a military air defense operational computer, as the teaching medium.

Following this feasibility study, the Aerospace Defense Command requested that SDC undertake a project to implement this type of training into the BUIC III advanced air defense system. The Air Force termed this training concept Automated Programmed Instruction, or API. The reason for using the term API rather than the acronym CAI which stands for Computer-Assisted Instruction was that API was totally based on the teaching concepts of programmed instruction, as developed during the 1950's. The SDC Automated Programmed Instruction training vehicle therefore was an application of proven training concepts and advanced computer technology. In API training the computer presents instructional information to the student, quizzes him as to how well he learned the information, presents an immediate feedback as to the correctness of his response, and when he makes an error, provides remedial instructions.

API commenced to be integrated into the BUIC III operational air defense system in 1969. For the next year it was available for use at selected BUIC III operational defense control centers throughout the United States. Before it was fully implemented, however, API was dropped from the BUIC III Operation System due to budgetary and personnel cutbacks in the command. Nevertheless, SDC's preliminary validation tests of API proved it to be an outstandingly effective training tool. Air Force personnel were enthusiastic about this form of training, and validation tests results affirmed criterion tests were met.

API was designed for integration into the system on the basis of several operational criteria. First and foremost, the Air Force specified that API was to run concurrent with live air operations. In other words, live air defense was to be conducted simultaneous with the conduct of API at the BUIC III center. Each BUIC control center has ten consoles, one of which could be placed in the API training format, while the remaining nine were used to conduct live air defense. The API data was thus never mixed with the live data being processed in the center.

Of course the live system had precedence over API training at all times. An example of this is that in the event an emergency occurred in the live system or, when the BUIC control center received an excessive amount of live radar returns, in these and like instances API was terminated and removed from the system automatically and instantaneously. The console assigned to API training was also instantaneously returned to normal live operations.

API, therefore, was gainfully employed concurrent with the center's live air control responsibility but without interfering or impinging on the operational requirements of the BUIC system. Even though only one console was used for API training at each center, approximately 12 hours of each day could be used for API training purposes at each location.

Another functional criteria in the development of API and certainly one of the most advantageous features from a cost-effectiveness viewpoint was that API used existing air defense computer programs. It used the existing tracking program, the existing display program, and the existing tactical weapons program. API, from a computer programming viewpoint, was relatively simple to develop, making maximum use of the existing operational system. The API concept was, therefore, basically cost-effective to develop calling for a relatively small amount of original computer programming. Also, by using the operation computer programs to process the training data, very realistic training situations were achieved. The simulated interceptor was guided to its target in an API training situation exactly as if it was an interceptor on time-division data link, because the operational computer program processed the API data the same way that it processed live data.

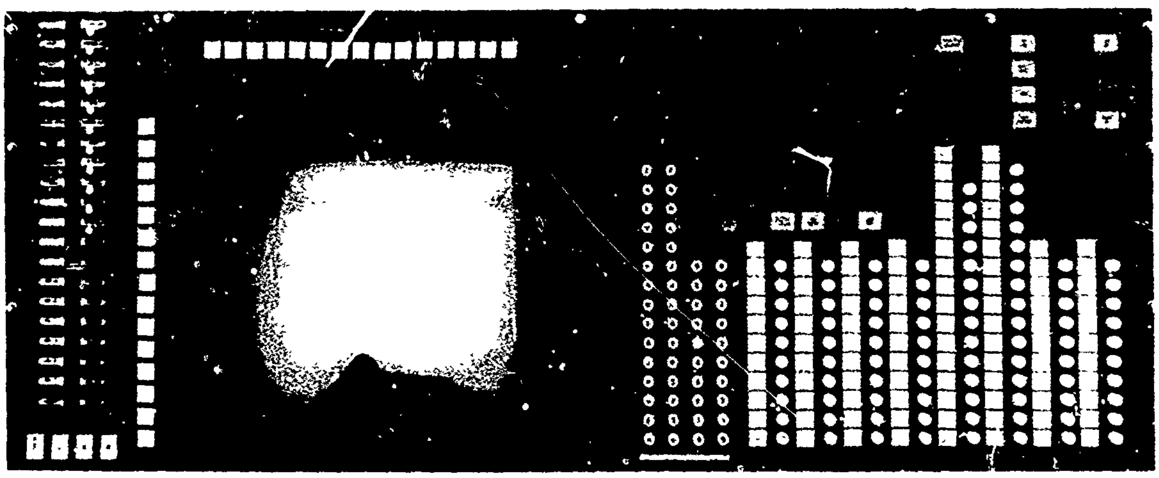

Figure 1. BUIC III Console Picture

Another obvious advantage of the API concept was that it used the same operator console as used in live air defense (see figure 1). The trainee used the identical switch actions and the identical light sensor actions as he did to conduct live air defense. The trainee did not, therefore, have to learn to manipulate a unique teaching machine to be able to take API training. The console was used to train the operator to take the same actions, interpret the same alpha numeric data presented on the situation display or SID and make the same decisions as called for in his particular operational position.

In using the operational Air Defense Program or ADP (see API System Flow Chart), which runs on a real-time basis, prevision was made to "freeze" the API air picture for an indefinite length of time allowing the trainee to self-pace his own response to the training objective being presented. (See figure 2.)

Generation of API course material was also done from existing computer programs. In this case API courses were produced using the BUIC Exercise Prep-

aration System or BEPS. With minor modification to the BEPS program, eight different API courses were generated at SDC's Santa Monica facility accounting for approximately 24 hours of concentrated site specific training materials. In addition to modifying BEPS and ADP the BUIC Operational Recording Tape (BORT) and the BUIC Analysis Reduction System (BARS) were also slightly modified to accept, record and printout data concerning student progress, errors, time latencies, and box scores.

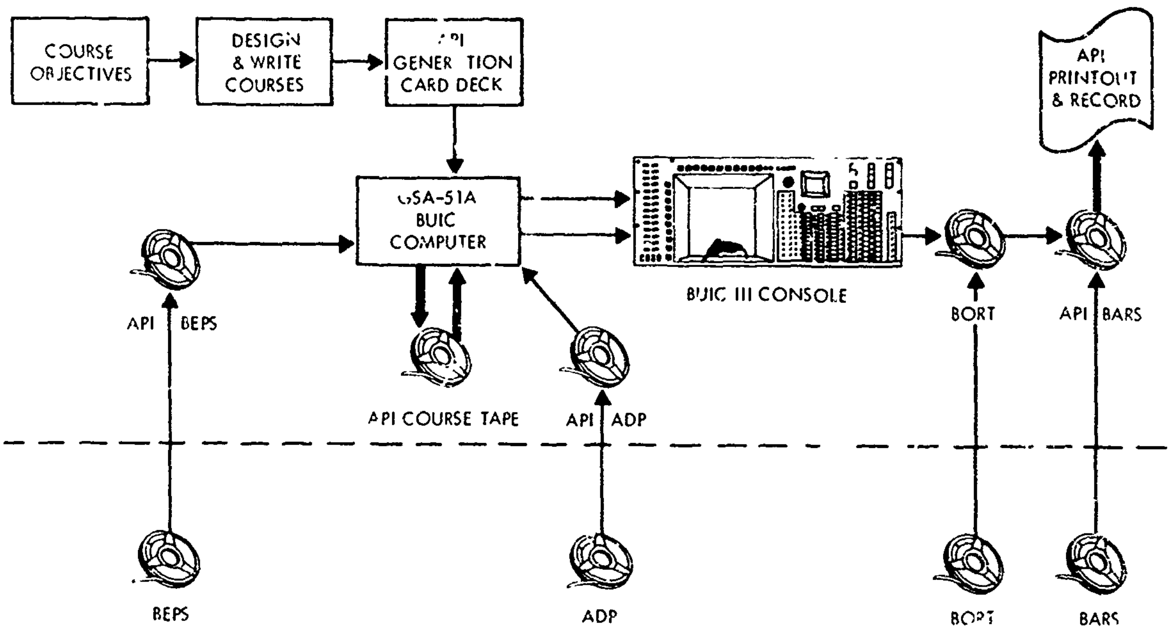

Figure 2. API System Flow Diagram

Each course was stored on an individual computer tape. The courses were broken into 15 to 30-minute lessons so the student would have logical break points, thereby, avoiding long attention-span problems. Because of the self-pacing feature of API, a trainee working at an API console could stop his API training lesson at any point to accomplish other tasks, such as answering a phone, and then return to the console, take a continue action and without further adieu go right on through the training program.

All courses were based on a 3-part mixture. First, basic instructional information was presented to the trainee. Secondly, the trainee was asked to take operational switch actions identical to those found in live air and third, the trainee was presented multiple choice questions. The method of presenting this information was done on an individualized basis with regard to the position being trained.

A Weapons Director trainee was taught weapons direction, an Air Surveillance Operator was taught air surveillance operations, and so on. Remedial training loops were built into each course as determined necessary by field trials conducted by the course designer. If a trainee made a critical error, while going through an API course, remedial training was automatically given to clarify the point being taught and to help assure that the trainee would benefit from the rest of the course.

Now that the basic objectives and methods of operation of automated programmed instruction have been presented, let's take a look at it from the viewpoint of the trainee.

The BUIC III console is a rather complex piece of equipment to master. The SID picture shown here (see figure 3) is taken from the Weapons Director Course and is providing the trainee information regarding the Selective Identification Feature (SIF) number switch action. This example is taken from the Cape Code environment where BUIC III site Z10 is situated. Once the trainee has read this information he will take the "continue" action which is a single button switch action. The continue action will force the API course into the next frame of instruction. The English text that is displayed on the scope is unique to API. The operational display does not have English textual information on it.

Following the reading of this information the trainee will continue on to the next frame of instruction.

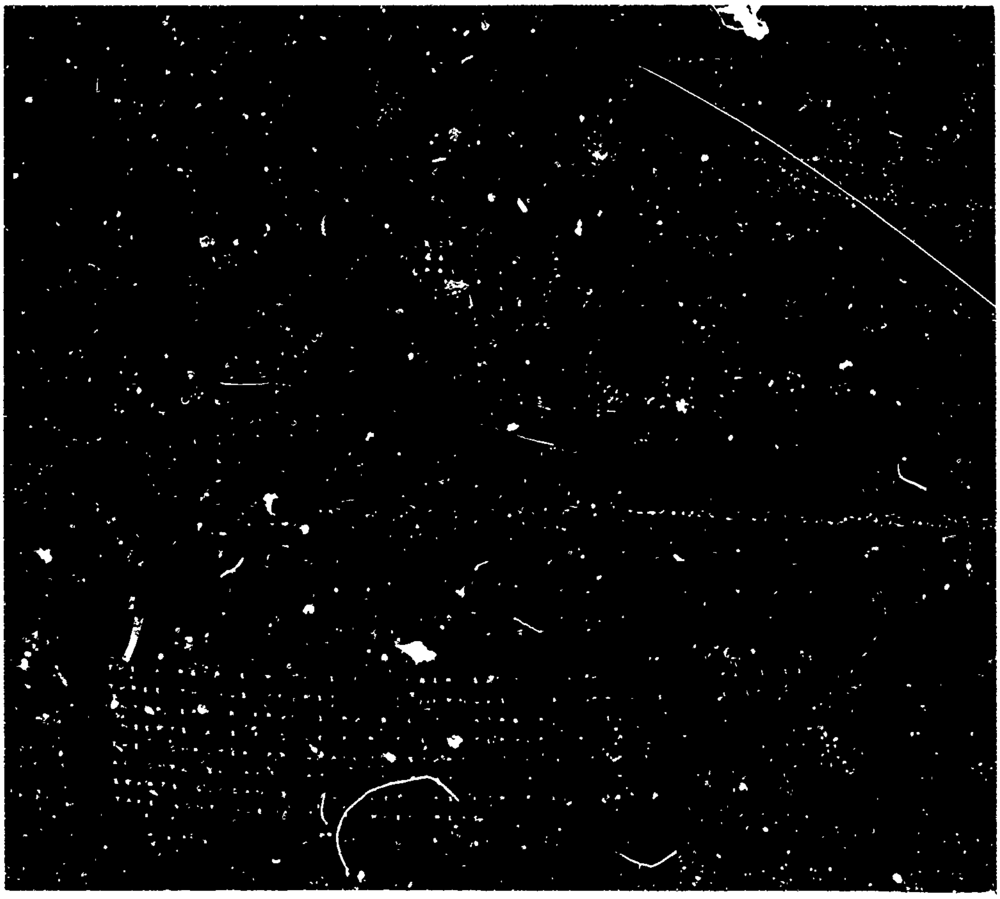

Figure 3. BUIC III SID Picture - Text Display

In this case (see figure 4), the next frame of instruction is a multiple choice question based on the information just provided to the trainee. Once the trainee has read the question and selected the answer he thinks is most appropriate he will light sensor the dot to the left of that answer.

Once he has light sensored his answer he will be provided with feedback as shown here at the top of the scope indicating whether he was right or wrong and informing him to continue on in the course.

In this case the trainee answered correctly and he is informed that the system will now explain how the action is taken.

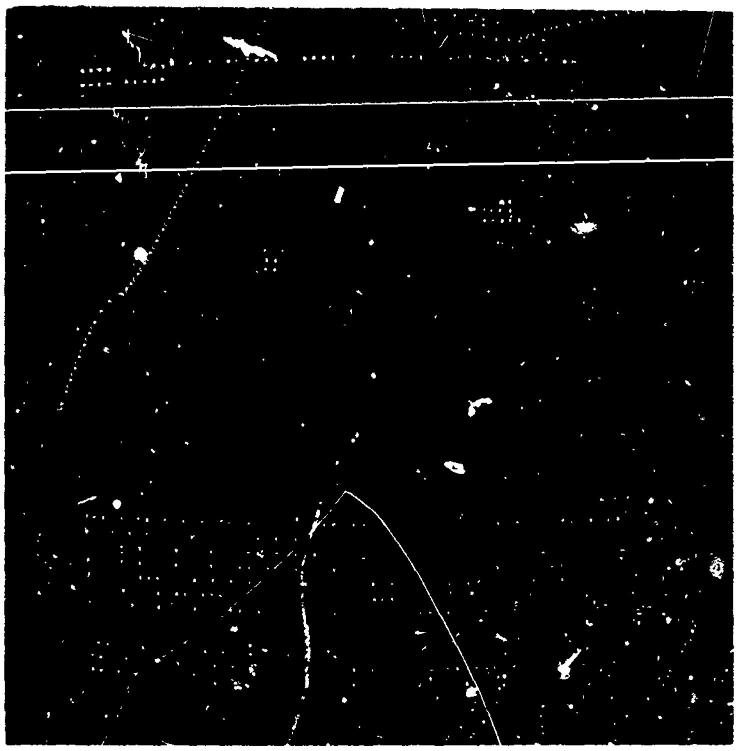

Figure 4. BUIC III SID Picture - Multiple Choice Display

The airborne with SIF number switch action is accomplished by several steps. These steps are pointed out on the scope (see figure 5), the trainee will take his time to read these instructions then insert into the console keyboard the proper button actions which constitute the operational action.

Lima Papa 01 is the interceptor he is working with in the center of the scope. The airborne with SIF number switch action combines the keyboard and the light sensor action. Here the trainee has just light sensored the track. He has received feedback telling him once again good, he took the proper action. When the trainee takes the proper action the aircraft symbology goes airborne, exactly as it would in live operations. After taking the continue action the next frame of instruction asks the trainee to take this same action on a new interceptor without the cues present. He will do this purely by recall to reinforce the training he just received. If he fails to remember the proper actions, he will be recycled to the previous frame which contained the cues.

Following this sequence the trainee is once again provided information of a textual nature.

The eight API courses produced by SDC covered the areas of weapons direction, air surveillance, passive tracking, radar input countermeasures, and identification. Weapons, air surveillance and passive tracking each had elementary lessons for newly assigned personnel and advanced lessons built to stress experienced personnel who were classified as operational ready. The countermeasures and identification courses were both elementary courses.

The API concept of using operational computers, programs and data bases is still new in the world of training. Most computer based systems are designed for workloads which are seldom reached. The BUIC III system as an example is designed to combat a massive air attack. During daily operations the com-

puter is no where near being saturated in its workload. API took advantage of this fact and therefore extended the usefulness of the computer system while simultaneously assisting on-site training personnel in their task of ensuring effective operational status among all crew members.

Due to its individualized approach, API proved to be a very powerful training tool. Unlike a lecture, a movie, or a text book API forced the trainee to physically respond to instruction and immediately informed him of the correctness of his response. Only after the trainee has completed the lesson does he receive a box score on his SID and an off-line hardcopy printout of his performance in the course. This automatic printout was proof of the trainee having taken the course and proved useful to the on-site training officer in determining future training assignments.

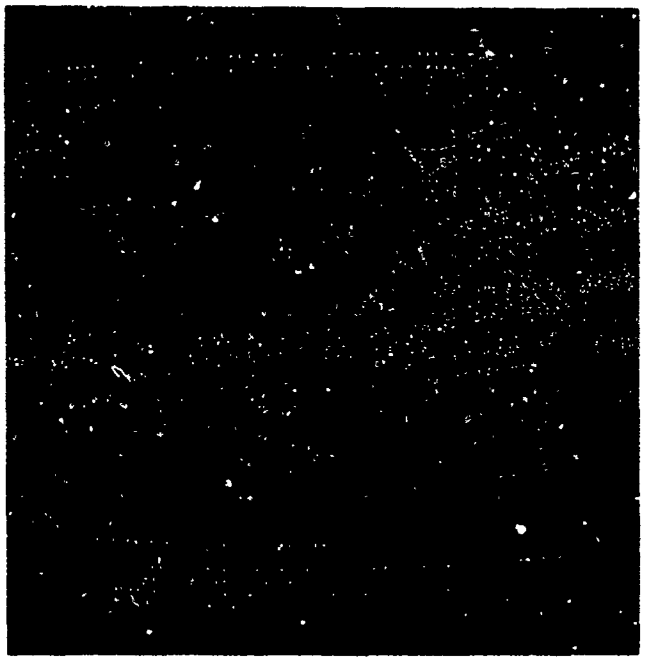

Figure 5. BUIC III SID Picture - Operational Action Display

The courses were system engineered to the point of teaching only those subjects which were critical to effective and efficient operator performance. No frills or attempts to use the computer as a replacement for a text book were included in our training course development. Because of this fact, and the subsequent direct carry over to live operations of the skills taught, all Air Force trainees exposed to SDC's validation runs of API expressed enthusiasm for this unique form of training. It's application to other operational settings seems evident.

A PRINTER PLOTTER PROGRAM FOR DIGITAL SIMULATION STUDIES

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Many computer simulation experiments involve the generation of large quantities of output data, resulting in extensive tables of numerical information. These tables are often difficult to interpret without considerable effort on the part of the reader, particularly with respect to the detection of variable trend perturbations in long strings of data. To alleviate this difficulty, a computer subroutine was developed to provide immediate printer plots of data arrays generated in simulation program runs. These plots allow the immediate examination of experimental run results, and provide the user with an easy-to-read tool for determining requirements for additional computer runs.

The program will plot up to five simultaneous data curves, with automatic plot variable scaling on each curve to achieve maximum output resolution in each instance. If the user wishes to plot any number of curves less than the five maximum allowed on a given set of axes, it is only necessary to fill the unused arrays appearing in the call statement with some common constant value, and the curve for this array or group of arrays will not be plotted. Similarly, simulation program outputs with more than five variables can easily be accommodated with multiple calls to the plotting program.

The plot routine was written in IBM 1130 FORTRAN, but should be acceptable to any FORTRAN compiler with an alphanumeric capability and provisions for a DATA statement. In fact, the authors use the same program deck on both IBM 1130 and IBM 360/65 computer runs, with the only change required being the appropriate selection for the FORTRAN logical unit number for the output printer. A complete listing of the program appears in figure 1.

The plotter is called from the data generation program with a statement of the following form:

```
CALL YPLOT(NPTS, A, B, C, D, E, X, IFLAG)
```

where: NPTS = scaler integer variable giving the number of points to be plotted. The subroutine presently uses variable dimension array allocation to conserve memory requirements, and the reader should be aware that this feature may cause difficulties in other FORTRAN implementations.

A, B, C, D, E, = one dimensional FORTRAN arrays of length 'NPTS' containing the data points to be plotted.

X = one dimensional FORTRAN array of length 'NPTS' containing the values of the common independent variable values for each of the five data curves.

```
FORTRAN IV G LEVEL  19                YPLOT           DATE = 71177       14/34/24            PAGE 0001

0001            SUBROUTINE YPLOT  (M,AA,BB,CC,DD,EE,ZZ,KK)
0002            DIMENSION  X(100)
0003            DIMENSION  AA(2),BB(2),CC(2),DD(2),EE(2),ZZ(2)
0004            DATA  BL,A,B,C,D,E,DOT,DASH/' ','A','B','C','D','E','I','-'/
           C    FOLLOWING CARD SETS FORTRAN LOGICAL UNIT NUMBER FOR PRINTER...
0005            J = 6
0006            AMIN = AA(1)
0007            AMAX = AA(1)
0008            BMIN = BB(1)
0009            BMAX = BB(1)
0010            CMIN = CC(1)
0011            CMAX = CC(1)
0012            DMIN = DD(1)
0013            DMAX = DD(1)
0014            EMIN = EE(1)
0015            EMAX = EE(1)
0016            DO 555 N=1,100
0017        555 X(N) = BL
0018            DO 35 I=1,M
0019            IF ( AA(I) - AMAX) 10,11,11
0020         11 AMAX = AA(I)
0021         10 IF (AA(I) - AMIN) 12,12,13
0022         12 AMIN = AA(I)
0023         13 IF (BB(I) - BMAX) 20,21,21
0024         21 BMAX = BB(I)
0025         20 IF (BB(I) - BMIN) 22,22,23
0026         22 BMIN = BB(I)
0027         23 IF (CC(I) - CMAX) 24,25,25
0028         25 CMAX = CC(I)
0029         24 IF (CC(I) - CMIN) 26,26,27
0030         26 CMIN = CC(I)
0031         27 IF ( DD(I) - DMAX) 28,29,29
0032         29 DMAX = DD(I)
0033         28 IF (DD(I) - DMIN) 30,30,31
0034         30 DMIN = DD(I)
0035         31 IF (EE(I) - EMAX) 32,33,33
0036         33 EMAX = EE(I)
0037         32 IF (EE(I) - EMIN) 34,34,35
0038         34 EMIN = EE(I)
0039         35 CONTINUE
0040            AWID = AMAX - AMIN
0041            BWID = BMAX - BMIN
0042            CWID = CMAX - CMIN
0043            DWID = DMAX - DMIN
0044            EWID = EMAX - EMIN
0045            AUNIT = AWID / 100.
0046            BUNIT = BWID / 100.
0047            CUNIT = CWID / 100.
0048            DUNIT = DWID / 100.
0049            EUNIT = EWID / 100.
0050            AMID = AWID / 2. + AMIN
0051            BMID = BWID / 2. + BMIN
0052            CMID = CWID / 2. + CMIN
0053            DMID = DWID / 2. + DMIN
```

Figure 1. Plotter Program Listing (1 of 3)

```
FORTRAN IV G LEVEL  19                YPLOT           DATE = 71177       14/34/24            PAGE 0002

0054            EMID = EWID / 2. + EMIN
0055            NK = 1
0056            DO 1000  L = 1,M
0057            Z = L
0058            IF ((L/10) - (Z/10.))  40,41,40
0059         41 DO 223  LL = 1,100
0060        223 X(LL) = DASH
0061         40 X(1)  =DOT
0062            X(25)  = DOT
0063            X(50) = DOT
0064            X(75) = DOT
0065            X(100)= DOT
0066            IF (AUNIT) 90,93,90
0067         90 KA = (AA(L) - AMIN) / AUNIT
0068            IF (KA)  91,91,92
0069         91 KA = 1
0070         92 X(KA) = A
0071         93 IF (BUNIT) 94,97,94
0072         94 KB = (BB(L) - BMIN) / BUNIT
0073            IF (KB) 95,95,96
0074         95 KB = 1
0075         96 X(KB) = B
0076         97 IF (CUNIT) 98,101,98
0077         98 KC = (CC(L) - CMIN) / CUNIT
0078            IF (KC)   99,99,100
0079         99 KC = 1
0080        100 X(KC) = C
0081        101 IF (DUNIT) 102,105,102
0082        102 KD = (DD(L) - DMIN) / DUNIT
0083            IF (KD) 103,103,104
0084        103 KD = 1
0085        104 X(KD) = D
0086        105 IF (EUNIT)106,109,106
0087        106 KE = (EE(L) - EMIN) / EUNIT
0088            IF (KE) 107,107,108
0089        107 KE = 1
0090        108 X(KE) = E
0091        109 IF (NK - 1)  151,152,151
0092        152 WRITE (J,111) AUNIT, BUNIT, CUNIT,DUNIT,EUNIT,
               1  AMIN, AMID, AMAX,
               2 BMIN, BMID, BMAX,
               3  CMIN, CMID, CMAX,
               4 DMIN, DMID, DMAX,
               5 EMIN, EMID, EMAX
0093        111 FORMAT('1'    ,'EACH UNIT ON THE Y -AXIS  =  ' ,
               1  F10.5,'  FOR EQ. A  ,   ',3X,F10.5,'  FOR EQ. B  ,   ',3X,
               1  F10.5,'  FOR EQ. C  ,  ',3X,/,T31,F10.5,'  FOR EQ. D  ,  ',3X,
               1  F10.5,'  FOR EQ. E ',
               2 5(/,F15.5,T45,F20.5,T95,F20.5),
               3 /,T10,'+',T59,'+',T109,'+',/,T10,100('-'))
0094        151  IF  (KK)  155 , 156 , 155
0095        156 WRITE  (J,116) L,(X(MM),MM=1,100)
0096        116 FORMAT (1X, T6, I4, 100A1)
0097            GO TO  77
```

Figure 1. Plotter Program Listing (2 of 3)

```
FORTRAN IV G LEVEL  19                YPLOT            DATE = 71177        14/34/24          PAGE 0003

      155 WRITE(J,117)  ZZ(L),(X(MM),MM=1,100)
      117 FORMAT (1X, F8.2,100A1)
       77 IF ((L/10) - (Z/10.))  45,46,45
       46 DO 47  KL = 1,100
       47 X(KL) = BL
       45 IF(NK - 50)  153,154,154
      154 NK = 0
      153 NK = NK + 1
          IF (AUNIT)   400,401,400
      400 X(KA) = BL
      401 IF (BUNIT)   402,403,402
      402 X(KB) = BL
      403 IF (CUNIT)   404,405,404
      404 X(KC) = BL
      405 IF (DUNIT)   406,407,406
      406 X(KD) = BL
      407 IF (EUNIT)   408,1000,408
      408 X(KE) = BL
     1000 CONTINUE
          RETURN
          END
```

Figure 1. Plotter Program Listing (3 of 3)

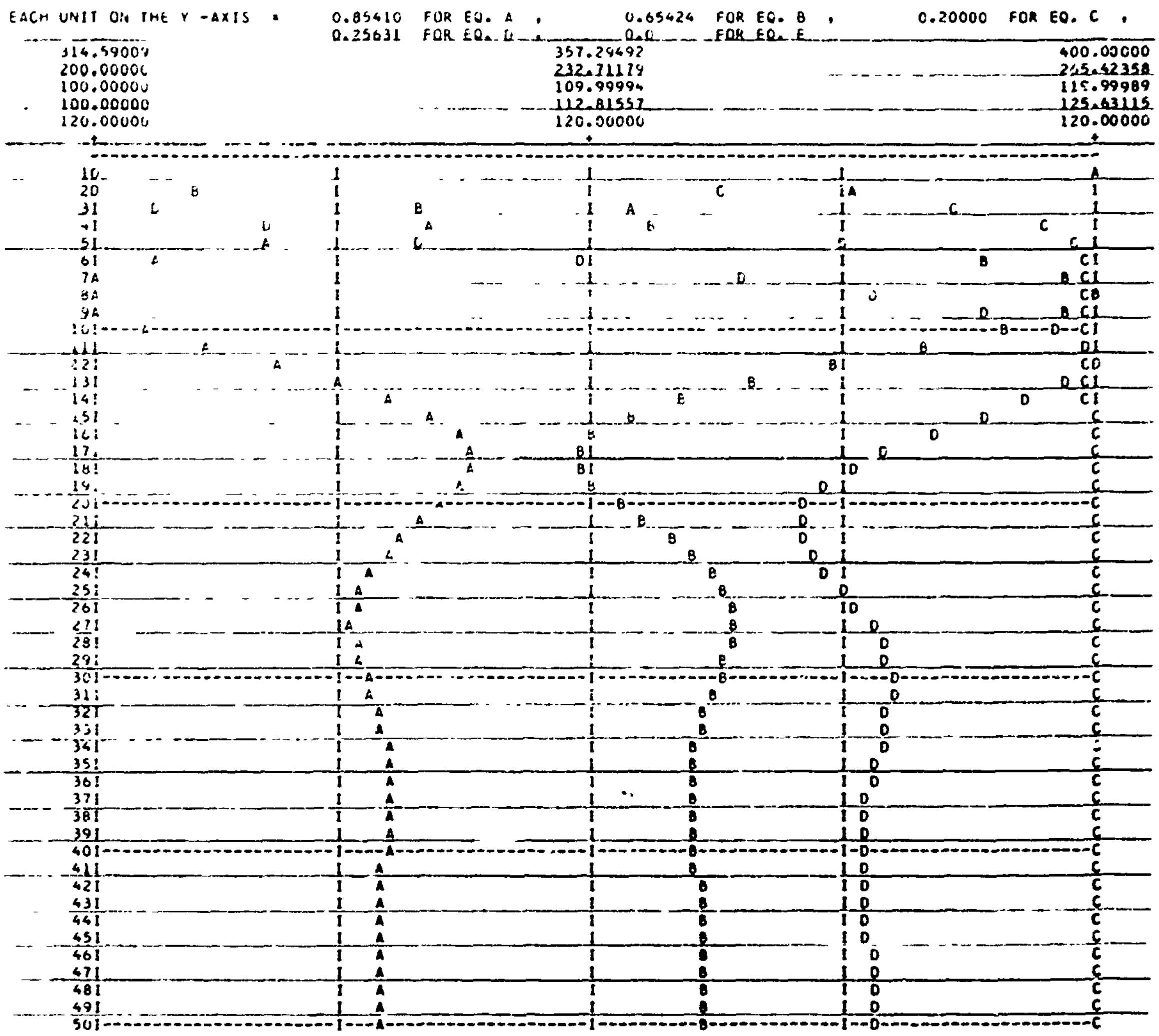

Figure 2. Plotter Output for Simulation Example

IFLAG = scaler integer control variable. If set equal to zero, the program will ignore the values in the X array and print an integer count of the data point numbers at the left of each row of the output plot. If set equal to one, the program will print the appropriate values from the X array at the left of each row of the output plot.

To illustrate the use of the program in a representative simulation study, consider the simple production-inventory system described in (1). The model equations are given in the reference in the DYNAMO Computer Language format, but may easily be converted to a state-variable differential equation following the procedure outlined in (2). Assuming a state vector definition of the form:

$$\underline{X} = \begin{bmatrix} X1 \\ X2 \\ X3 \\ X4 \\ X5 \end{bmatrix} = \begin{bmatrix} \text{Retail Inventory} \\ \text{Factory Order Backlog} \\ \text{Averaged Retail Sales} \\ \text{Production Ability} \\ \text{Retail Sales} \end{bmatrix}$$

the simulation model then becomes the fifth-order system:

$$\dot{\underline{X}} = A\underline{X}$$

with

$$A = \begin{bmatrix} 0 & 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & -1 & 0 \\ 0 & 0 & -1 & 0 & 1 \\ 0 & .125 & 0 & -.25 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

A state-transition matrix data generation program was used to exercise the model with the initial conditions specified in the reference over a time frame of 0 to 49 units and a step size of 1 unit, giving a total of 50 state vector output points of 5 components each. The state vector values were incrementally loaded into the plot arrays as the simulation progressed. The plotter routine was called at the end of the numerical processing, with the results shown in figure 2. The first four curves, representing the first four components of the state vector, were plotted with the characters A, B, C, and D respectively. The minimum, maximum, and mid-point values for each curve appear at the top of each page of the output in ascending order. Note that the values for E are constant at a level of 120.000, indicating that the fifth state vector component remained at this constant value throughout the run. This aspect of program behavior is also used when plotting less than the full complement of five curves, as the data in a constant vector would plot as a straight vertical line, and are deleted from the plot output to maximize readability. Also note that the plot in figure 2 used IFLAG = 0, and the data point count generated by the plotter appears in the left hand margin.

A brief note about the scaling procedures employed by the program is in order. Under normal operating conditions, scaling is accomplished automatically for each curve without user intervention. If, however, a common scale for each of the five curves is required, the main program must be structured to supply the upper and lower limits of each curve's plot scale in two entries appended to each data array, and to set the point counter to a value equal to the number of the actual data points to be plotted plus two to force the scaling section to consider the supplied values. In order for this procedure to work properly, the lower limit specified must be less than or equal to the smaller expected data point, and similarly, the upper plot limit must be greater than or equal to the largest expected data point.

References

(1) Jarmain, W. E., ed., Problems in Industrial Dynamics, MIT Press, 1963, pp. 118-124.

(2) Bauer, C. S. and Capehart, B. L., "State Variable Methods for Digital Simulation of Economic and Inventory System Models," paper presented at the 38th National Meeting of the Operations Research Society of America, October, 1970

REAL-TIME SPECTRUM ANALYSIS OF SONAR SIGNALS USING A COMPUTERIZED ACOUSTIC ANALYSIS SYSTEM

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For some time, the sea-going computer has been proving its worth in a wide variety of applications.[1,2] In this presentation, we describe an acoustic analysis system built around a small general-purpose computer, and consider the role it has played, and the influence it has exerted in extensive at-sea tests of a sophisticated sonar system. Particular attention is paid to the use and value of on-line acoustic data in improving operator effectiveness in Research, Development, Test and Evaluation (TDT&E).

The acoustic analysis system, Hydrospace Research Corporation System 1360, is shown in its shipboard installation in figure 1. The system is a specialized hybrid of analog and digital subsystems organized so as to provide effective acquisition, on-line processing and output of acoustic data in standard format, for immediate use by the operator. This capability is of obvious value in field experimentation as well as in operational usage. Based on the on-line spectral data, the operator or experimenter can verify overall acoustic system performance over the frequency range of interest, detect abnormalities, modify procedures, etc. In addition, the ability to acquire, present, and compare data under changing conditions in the course of exercises, constitutes an effective mechanism for training and familiarization of new personnel with sonar information in general and with specific characteristics of acoustic gear.

To illustrate the benefits of a rapid on-line analysis capability from the standpoint of operator effectiveness, we should first outline certain unique aspects of the sonar evaluation program referred to above.

The sea-trial series in which the acoustic analysis system was initially employed was basically an extended Reliability and Maintainability evaluation of a state-of-art sonar. The R & M program was undertaken in order to identify and investigate possible deficiencies in this aspect of the sonar system performance so that corrective measures could be applied in the development of production specifications and in the production phase. Due to the nature of the system and the R & M objectives, the evaluation program necessarily involved a great deal of at-sea test time over an extended period.

Figure 1. Computerized Accustic Analysis System in Shipboard Installation

From a technical standpoint, the R & M program obviously offered an excellent opportunity for in-depth acoustic performance investigation as a follow-up to previous developmental work. From a personnel standpoint, however, the extensive sea-time planned for the R & M work added certain constraints.

For both technical and economic reasons, the senior engineering personnel most familiar with the system under test, and with the characteristics of the acoustic data obtained from it, could not participate heavily in the continuing at-sea work. The R & M tests, however, demanded that large quantities of valid acoustic data be obtained routinely. In addition, it was essential that the results of additional R & D investigations be available on a timely basis, for optimum value to the continuing developmental effort.

These were rather demanding program requirements for the technical field crew. Any lack of experience, at least, in the acquisition and analysis of acoustic data, would obviously jeopardize program objectives. Conventional on-line acoustic analysis is usually accomplished by producing a strip chart recording of one-third octave filter band levels, in db re 1 volt, using either a multi-channel recorder and parallel filters, or a single channel analyzer with a mechanically swept filter. In either case, it is necessary to calibrate the recorder, read off the band levels in dbv for each band, usually with some eyeball averaging, and apply the appropriate corrections for hydrophone sensitivity, system gain and, if desired, bandwidth, to produce spectral information in acoustic units such as db re 1 microbar in a 1 Hz band. This is not only tedious and time consuming, but also involves considerable opportunity for introduction of human errors. If, as is usually the case, the data must be plotted for analysis and presentation, and subjected to further statistical analysis, the amount of time and effort involved becomes formidable.

In view of the amount of data required in the sonar evaluation, with the most experienced personnel unavailable for extended work in the field, the acoustic measurement requirements posed a significant problem. An effective solution was found in the computerized acoustic analysis system, which was shown in figure 1. This system was installed on the HRC test vessel R/V DANIEL L. HARRIS, a converted sub chaser, in the summer of 1968, and has operated reliably in both R & M and R & D investigations through an extensive and continuing series of sea trials. It has been removed and reinstalled several times during ship overhauls and other interim periods, and has survived several storms, and a generally rugged environment while satisfying the stringent program requirements for a large quantity of high-quality acoustic data on a short time scale. Before considering the impact that the on-line processor has had on the field tests, and specifically on the effectiveness of the technical crew, we will outline pertinent aspects of its design and operation. (The system and its capabilities have been described in detail previously).[3]

As shown in the block diagram in figure 2, the acoustic analysis system is built around a small general-purpose computer, and includes conventional one-third octave filter sets, a high speed multiplexer and A to D converter, digital plotter and teletype. (We might note at this point that although the following discussion centers on the "traditional" and widely used one-third octave analysis, software packages have been developed for the 1360 to provide alternate processing modes. Some of these additional capabilities are described below).

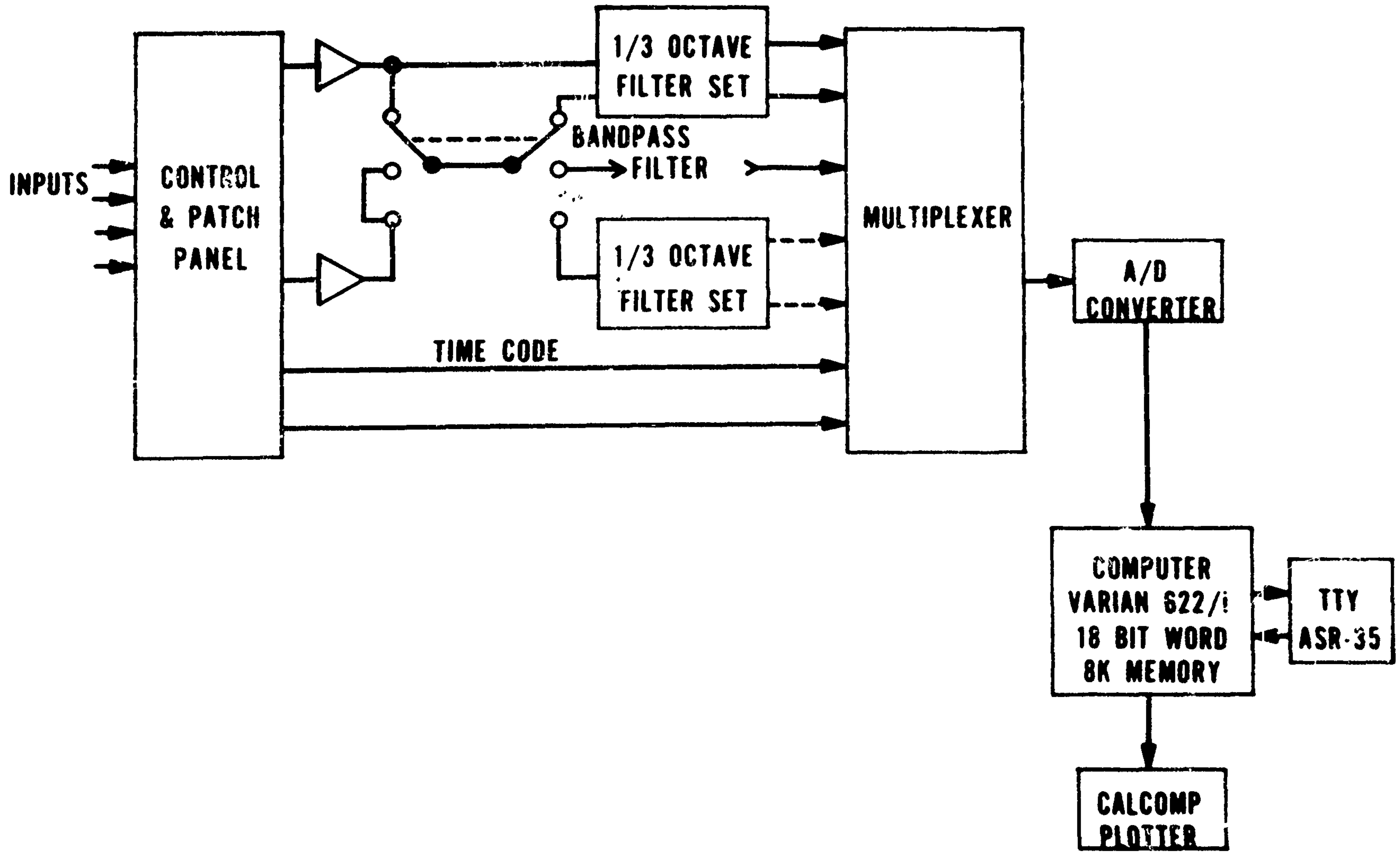

Figure 2. Acoustic Analysis System Block Diagram

For spectrum analysis in one-third octave filter bands, the normal processing procedure involves:

1. Squaring the output of a particular filter;
2. Integrating; and,
3. Converting to the logarithmic scale.

With calibration and system gain correction, the resulting band level can be expressed in decibels referenced to an appropriate sound pressure unit. The conventional output, then, is a plot of band levels for the one-third octave band center frequencies, over the frequency range of interest. Since there are 10 such bands per decade of frequency range, it is clear that conventional processing involves either a great deal of analog hardware for parallel processing, or low processing speeds, as a single processing channel is applied in turn to all filter bands of interest. Neither of these alternatives are favorable for on-line work in the field.

These drawbacks are avoided in the 1360 by taking advantage of the high-speed capabilities of the digital computer to execute the necessary signal processing steps, i.e., squaring, integration and log conversion, on the digitized outputs of conventional one-third octave filters. This hybrid approach, combined with a unique sampling technique, increases the overall frequency range, or total number of one-third octave bands, that can be processed essentially simultaneously.

The filter outputs are applied in parallel channels to the multiplexer/A to D converter, where they are sampled, digitized, and entered into the computer in sequence, under program control. Normally, the upper frequency limit for valid processing depends on the channel scan rate at which the filter outputs are sampled. This establishes the Nyquist frequency for the sampling process. In the present case, due to processing time required for each digitized input, this is limited typically to the order of 200 scans of 40 channels per second.

In the 1360, the sampling rate restriction is avoided by the device of randomizing by computer control the initial channel, or effectively the initial frequency band, sampled in each scan. This has the effect of increasing the upper frequency limit, at which valid measurements can be made, to a frequency given by the conventional Nyquist frequency multiplied by the number of channels, or filter bands, covered in each scan. The upper limit is increased still further by injecting a random delay, equal to some fraction of the basic sampling interval, between consecutive scans.

The net effect of this random sampling scheme is the ability to make valid acoustic measurements, with no aliasing errors, to frequencies as high as 100 kHz, in spite of channel scan rates on the order of only 200 scans per second. For a given sensor or sonar output, measurements can be made over an operator-specified frequency range at a rate limited basically by the operator-specified integration time. Such measurements can be retained in a designated section of core memory for later use, or can be printed, plotted, or transferred to punched paper tape. (The output operations, of course, add to the basic time requirement for a given measurement if they are performed on-line).

The resulting system is a powerful analytical tool that combines compactness, essential to field operations, with flexibility of operation built into the basic processing software package. Before considering the soft-

ware provisions for operator-machine communication, we might review briefly the physical configuration of the system as it has been employed in the sonar program. In its original shipboard configuration, shown in figure 1, the entire system, with the exception of the teletype, was mounted in a standard 19" instrument rack. With the teletype at right angles to the main rack, the seated operator has convenient access to all controls essential to the operation of the system, and can readily monitor output data.

Subsequently, the digital plotter shown in the photograph was removed to another rack and replaced by a pair of buffer amplifiers and a patch panel. This was a data quality control measure, so that the operator of the acoustic analysis system has complete control over selection of the sonar signal to be measured and over gain setting. This was found to be highly desirable to alleviate a human error problem in a normally hectic environment. The desired acoustic signal can be selected either manually, or by computer-controlled relay based on an operator-specified identification number. At present, the main rack also includes a high-speed paper tape reader, not shown in figure 1, for input of programs or previously acquired spectral data for further processing.

Flexibility of operation is achieved via teletype control of basic processing parameters and functions. Software development and refinement have continued throughout the program, leading to a powerful conversational operator language known as SPECTRAL, with an extensive complement of keyboard commands.[3] This approach maintains simplicity of operation while providing effective operator control. The sample computer-generated teletype copy shown in figure 3 suggests the flexibility of the SPECTRAL one-third octave analysis program. The first part of figure 3 contains examples of status logs, which are printed on request through the keyboard, or as specified in an operator program.

The "Quick Log" at the top of figure 3a is obtained by a two-letter command entered on the teletype keyboard. It lists all parameters pertinent to the one-third octave program. For example, "F" indicates the first filter band, or effectively the lower frequency limit, to be included in the spectral analysis. "N" specifies the number of filter bands to be sampled, and "I" is the integration time. (The latter is shown as 1 second in the example, but is naturally much greater than this in normal processing). Other letters designate the origin, vertical scale (db per division), and plotting symbol to be used by the digital plotter, run number, sonar output to be processed, etc.

Below the "Quick Log", several individual status logs are listed. This is an operator convenience, allowing a check of an individual parameter, when the entire listing is unnecessary. Each individual log is requested by striking "L" followed by the corresponding designator letter.

Each of the processing, or run parameters shown in the "Quick Log" can be incremented or otherwise changed by the operator. A two-letter command informs the machine that a new condition is to be established, and the operator then enters the new value for the designated parameter via the keyboard. For example, "EI" followed by "60" establishes an integration time of 1 minute for subsequent measurements.

An additional set of two-letter keyboard commands controls program functions. For example, the operator can initiate an integration or measurement of filter band levels, request a print-out of band levels, subtract a reference spectrum from the measured spectrum, and produce a plot or overplot of spectral data.

```
QLOG
1 A      Ø B     1 C     Ø E     3 F     Ø K     Ø J
Ø L      1 N     3 R     Ø S     Ø T     Ø.Ø G   1.Ø I
3.Ø O    1.2 V
```

```
LOG HYD.#     1
LOG EVENT     Ø
LOG BRG       Ø
LOG TICK      Ø
```

a. Quick-Log and Status Logs

```
      PROG.
100 ACQU:
101 SUB # 51:
102 BLVLS:
103 REPLOT:
104 P.TAPE:
105 END:
200
```

b. Simple Operator Program

Figure 3. Sample Teletype Copy

In the conduct of an experiment, then, the acoustician, engineer, or technician needs only a listing of the letter designators associated with the various parameters and controls. As far as possible, these have been selected based on a mnemonic relation to the corresponding function.

Figure 3b illustrates an additional level of automation available in the system software through an operator programming mode, in which a series of procedures, parameter changes, output functions, etc., can be specified in advance, using the keyboard instructions described above. The system will then perform the specified series of operations upon an instruction to execute the program. Such programs can be made to run repetitively, if desired, as a further convenience to the operator in a repeated series of identical measurements. The operator program in figure 3b initiates an "acquisition" or integration of band levels, subtracts a reference spectrum, and prints and plots the resulting spectrum. This is, of course, a very simple example and a much more complex sequence of operations, including DO loops, can be accommodated.

Several additional features were built into the basic analysis program. A calibration mode, for example, makes it possible to insert the various system functions, based on gain and hydrophone sensitivity, so that acquisition of an appropriate calibration voltage automatically calibrates the analysis system. Measurements can then be obtained directly in sound pressure level referenced to the desired units. Gain changes can be accounted for through the keyboard. If desired, range corrections, based on the

assumption of spherical spreading, can be automatically applied by designation of the desired range R in yards. Spectra can be stored in several reference locations, and manipulated, for example, to compute the difference between specified spectra. Data can be expressed as one-third octave band levels and/or corrected to equivalent 1 Hz spectrum levels. Spectra can be printed, punched on paper tape, plotted and overplotted, complete with coding symbols. Figure 4 shows a typical computer-generated spectral plot of one-third octave band level measurements (note that plotting symbols can be automatically incorporated in the plots if desired).

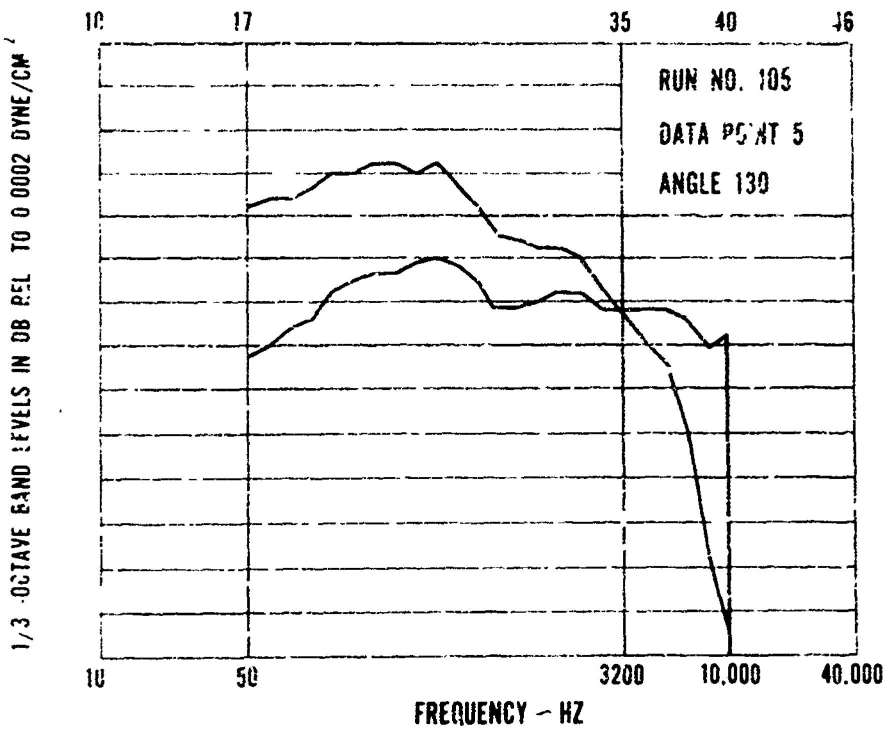

Figure 4. Sample One-Third Octave Measurement Plot

A separate extremely useful program is available for statistical analysis of spectral data, providing sample mean and standard deviation. The averaging can be done logarithmically, using data expressed in db, or linearly, following conversion from the db scale. As with the basic analysis program, results can be printed, punched on tape, and plotted in various combinations, and can be manipulated to yield additional useful plots such as sample mean with confidence limits based on the Student t distribution.

Other software packages have been developed to provide optional processing modes. It is possible, for example, to cross-correlate two acoustic signals, using parallel one-third octave filter banks. In general, the additional programs incorporate the same elements of flexibility and operator control as demonstrated in the basic one-third octave analysis program described above.

To conclude this description, we should point out that the acoustic processor is not limited to the physical configuration shown in figure 1, or to the application described in this presentation. A modular system has been built, using standard instrumentation housings, suitable for truck, or submarine installation. In this configuration, a truck-mounted system has been used in the field for aircraft noise measurements at airports or test facilities. Special software has been developed to produce on-line

measurements of Effective Perceived Noise level, in accordance with FAA specifications, and the system has been approved for aircraft-type-certification noise measurements. Finally, a much more elaborate shore-based version of the processor has been assembled in Hydrospace Research Corporation's (HRC's) laboratory. This incorporates a digital tape unit and magnetic drum, together with other refinements, and is currently employed in a major software development effort in support of the sonar evaluation program. Eventually, this system also will be re-configured for shipboard use.

We discussed previously the various problems related to personnel experience, data availability, etc. that were alleviated by the provision of an on-line analysis capability. We will attempt to complete the picture by reviewing specific effects of this capability from the standpoint of personnel effectiveness.

It should first be emphasized that training per se was not a direct objective of the program. Although, a brief orientation program was conducted, during a break in the trial series, the benefits in this area, which were derived from the provision of the acoustic analysis system in the shipboard laboratory, were essentially side effects. Undoubtedly, some of these effects could be considerably enhanced in a formal training program either in the field, or through simulation.

Based on our experience in the sonar evaluation program, the benefits referred to above may be summarized as follows:

1. Rapid familiarization of technical crew members with measurement operations alleviates problems due to unavoidable personnel turnovers and scheduling conflicts.

2. On-line availability of data plots, without tedious manual manipulations, improves understanding of sonar system performance and facilitates relationship of data characteristics with test parameters.

3. Processing speed and flexibility promotes operator participation in development or refinement of test procedures, data comparisons, etc.

4. **Calibration and measurement** with the computerized system enhance understanding of the computations involved in conventional on-line analysis techniques.

In short, the acoustic data itself and the operation of the sonar system under test become more meaningful in a shorter period of time. Also, due to the simplicity of operation of the analysis system, new members of the technical crew can be brought up to speed quickly on data acquisition, and optimum use of at-sea time can be achieved.

From another standpoint, it is perhaps obvious that, the same data that contributed to effective technical crew training was also available to benefit the sonar evaluation program more directly, through its quantity, quality, and timeliness. In addition, an operator feedback mechanism developed with increasing experience in the use of the processor and understanding of its potential. For example, rapid test procedures were devised to allow periodic checks of sonar system grooming, replacing time consuming and tedious conventional procedures. Test plans were arranged and runs were scheduled so

that the temporary storage capacity of the computer could be utilized effectively, for example in the generation of spectral overplots for the comparison of different test conditions. Finally, this feedback mechanism applied to the acoustic analysis system itself, providing a useful input in the development and refinement of software, and occasionally leading to modification or re-configuration of system hardware.

The provision of an on-line analysis capability, then, has contributed to an RDT&E field test program in two related but basically distinct ways:

a. Improved operator effectiveness; and,
b. Timely production of required data.

Based on these observations, we believe that an on-line processor can be applied to advantage in subsequent operational deployment as well as in a formal training program. A shipboard computerized processor can facilitate target identification, and allows rapid and efficient routine checks of sonar system grooming, self noise, calibration, etc. In addition, the immediate availability of spectral data contributes to an understanding of the effects of operational parameters on system performance, and provides an effective mechanism for continuing in-the-field training and review. Finally, in a formal training application, the processor leads to rapid familiarization of personnel with acoustic data, as well as with the procedures involved in the acquisition and analysis of such data. Full utilization of the speed and flexibility of the processor in conjunction with conventional or state-of-art sonar displays can undoubtedly enhance the trainee's understanding of sonar information and the capabilities and limitations of the sonar system.

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Ackrowledgements

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ELECTROACOUSTIC SIMULATION OF COMBAT SOUNDS PRESENT STATE-OF-THE-ART AND FUTURE GOALS

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INTRODUCTION

Electroacoustic simulation of combat sounds is of considerable interest in military training. The cost of weapons and ammunition, personnel required to operate the weapons, and danger to the trainee, are some of the reasons why the use of operational weapons for training activities is undesirable. The electroacoustic simulation of combat sounds such as rifle or artillery fire is a two-part process which requires recording the sound of the weapon to be simulated, and the electroacoustic reproduction of the sound recording. Advantages of the electroacoustic recording and reproduction of combat sounds are as follows:

a. Once the master recording of a weapon sound is made, unlimited copies of the recording can be made to supply numerous users as well as the establishment of a library of combat sounds, which would serve many training locations.

b. After the initial equipment investment, operation of a combat sound reproduction system is economical. Automation of the reproduction system can free instructors for other training functions.

Before the state-of-the-art technology in electroacoustic recording and reproduction systems can be discussed, it is necessary to define the nature of combat sounds, and the goal to be achieved in the electroacoustic simulation process. The sound produced when a rifle is fired is essentially a high intensity pulse of energy, which has a steep wavefront and rapid decay. Peak sound pressure readings of 180 decibels have been measured at the muzzle of a rifle as it is fired. Because of the sharp wavefront of the pulse, it is estimated that the bandwidth of the sound is from d.c. to beyond audibility (15 kHz). The subaudible component of the pulse produces a pressure wave that is felt rather than heard. The exact degree of electroacoustic simulation of combat sounds will largely depend on the end use of the simulation. To simplify the establishment of acoustic requirements for an electroacoustic simulator of combat sounds, three categories or degrees of simulation are defined as follows:

a. Highest degree of simulation in which exact simulation of sound intensity and bandwidth is required for simulation in an outdoor environment.

b. In training situations, where the trainee is close to the source of sound simulation, it may be desirable to limit the sound intensity to the established threshold of pain at 130 decibels so the trainee is not required to wear ear protectors to prevent hearing impairment. The simulated sound should have as wide a bandwidth as technology allows to achieve as much realism as possible. The training situation will also primarily be an outdoor one.

c. For classroom sound reproduction systems, high intensity, wide bandwidth sound reproduction is not required for classes in sound recognition. Smaller reproduction systems can be used to provide the bandwidth and sound intensity required for this purpose. This system will be smaller in size and lower in cost than systems required for outdoor simulation.

The sound emitted as a weapon is fired produces the sound distribution characteristics of a spherical sound source. The omnidirectional sound distribution of the combat sound is difficult to capture via the magnetic recording process and electroacoustic reproduction. Figure 1 is a graph of the attenuation of the sound pressure level versus the distance from the source of sound to the trainee. The sound pressure level generated by the electroacoustic reproduction system should be calculated to give the required sound pressure level at the trainee position. This calculation will provide the sound level requirement for the reproduction system's acoustical output capacity. Once the output capacity of the reproduction system is determined, selection of components for the reproduction system can be accomplished. A factor that is frequently overlooked is the attenuation of high frequency energy over long distances during high humidity weather conditions. Attenuation of high frequency energy will change the sound of the weapon as the distance of the sound source from the trainee varies. At a location close to the sound source, the weapon sound will have a sharper sound than that heard, when the trainee is at a greater distance, from the weapon. In the recording and reproduction process, it is important to capture as much of the full high frequency response of the combat sound as possible. The reproduction system will then generate a sharp pulse, which will receive high frequency attenuation, in travelling the distance from the simulator to the trainee. If the recording is made with the microphone at a considerable distance from the weapon, the sound heard from the simulator by the trainee will be excessively dull and unrealistic. Therefore, in the process of recording combat sounds it is important for the high intensity recording microphone to be placed as close to the weapon as possible in order to capture the full pulse spectrum.

CURRENT STATE-OF-THE-ART IN MAGNETIC RECORDING TECHNOLOGY

Recording combat sounds by the magnetic tape recording process requires a combination of high quality recording equipment, and skillful recording techniques in order to overcome the dynamic range limitations of magnetic tape. The dynamic range of real-life combat sounds is often in excess of 130 decibels. With the current state-of-the-art technology in magnetic recording, the maximum dynamic range is 70 decibels from a reference level of 3% total harmonic distortion to the ear weighted noise level of the tape. While the inability to record a 130 decibel dynamic range signal is disturbing, several techniques may be used to improve the recording. First of all, the ambient noise level at a location for recording combat sounds will probably be above 75 decibels. In addition to recording the sound of the weapon, ambient noise is also recorded. Therefore, the actual recording of the combat sound will have a peak signal to ambient noise ratio of 130 decibels minus 75 decibel ambient noise for an actual dynamic range of 55 decibels. Further improvement in the recording process can be achieved with the use of a peak limiter, which will cut-off peaks, above a preset level and prevent magnetic tape saturation. Adjustment of the peak limiter to provide peak limiting plus compression will enable a higher average signal level to be recorded without producing distortion and if the steep wavefront of the noise pulse is maintained, the trainee will probably not be able to detect that the peak is missing. Further improvement of dynamic range can be had with the use of the Dolby Compressor/ Expandor Noise Reduction System. An improvement of 15 decibels can be achieved with the Dolby unit to a maximum signal to noise ratio of 80 decibels. Use of the Dolby unit, during the recording and tape duplication process, can help maintain the dynamic range of the original recording.

Condenser microphones provide linear pickup of peak sound pressure levels as high as 180 decibels. The best transient response is obtained from a condenser microphone system using a 1/8-inch diameter diaphragm.

Frequency response of this condenser microphone is flat from 10 Hz to 100kHz and, therefore, the steep wavefront of a rifle shot can be maintained through the microphone transducer. However, the extremely low signal produced by the microphone requires a preamplification system with very low noise, and a high overload capacity to handle the peak signal amplitude.

CURRENT STATE-OF-THE-ART IN SOUND REPRODUCTION TECHNOLOGY

For this discussion of the current state-of-the-art in sound reproduction technology, the goal will be the best system to satisfy the simulation situation (a) defined earlier. The other simulation situations will all be variations of situation (a). In order to satisfy this training situation, the peak reproduced sound pressure level should approach 180 decibels with a bandwidth from below audibility to beyond audibility. The size and cost of such a reproduction system will be high.

Sonic boom simulators have been constructed that will produce 150 decibels at the subaudible threshold range. This simulator uses the mechanical rupturing of two diaphragm assemblies connected to a long exponential horn to produce an N shaped waveform. This simulator is limited to reproduction in the subaudible threshold range, and requires that the ruptured horn diaphragms be replaced before the simulator can be activated for a second time. Clearly, this type of simulation system would be unpractical for military training, where multiple explosions are often required.

The use of loudspeaker mechanisms for combat sound reproduction systems is difficult because of the performance limitations of loudspeaker mechanisms. In order to reproduce subaudible signals, the loudspeaker system has to move a great quantity of air. This requires a massive array of large diameter cone loudspeakers. The displacement required to reproduce a 20 Hertz signal for various diameter loudspeakers is shown in figure 2. Limiting this frequency range to that above 30 Hertz is a practical solution. Even at this frequency, a large quantity of air will have to be moved and multiple speaker arrays will be required. While a 15-inch diameter loudspeaker will move a greater quantity of air than a 12-inch unit for a given cone displacement, the increased mass of the loudspeaker cone will limit its ability to respond to a steep wavefront signal. Obviously, a series of different diameter loudspeakers will be necessary to preserve the waveshape and directional characteristics of the reproduction system. Figure 3 shows the effect of frequency on the directional distribution characteristics of a cone loudspeaker. Condition A is the distribution pattern produced, when the wavelength of the sound being reproduced is equal to 4 times the diameter of the loudspeaker cone. Condition B is observed, when the wavelength of the sound is equal to the diameter of the cone. When the wavelength of the sound is 1/4 the diameter of the cone, condition C results. The sound distribution pattern produced under condition C will be useless for sound reproduction systems that must cover a wide angle of sound distribution. A practical approach to the simulation of combat sounds is the use of a loudspeaker system using four different diameter driver elements. An array of four 12-inch low frequency speakers in a 16 cubic foot sealed enclosure will provide reproduction in the range from 20 Hz to 100 Hz.

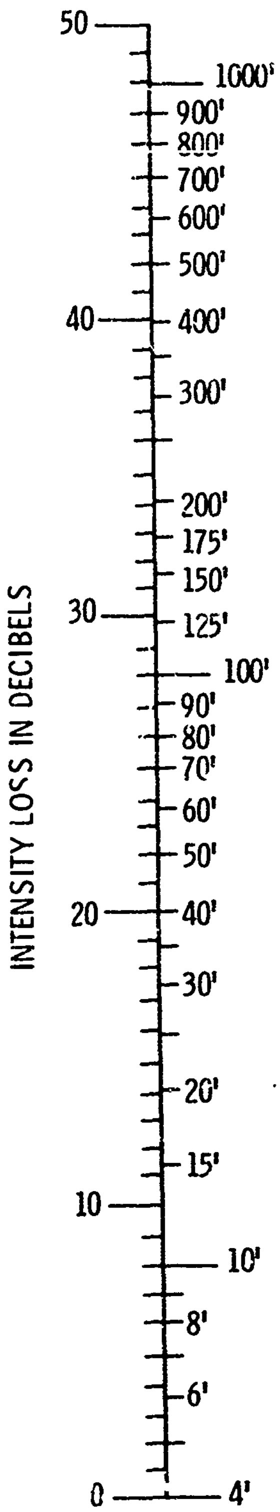

Figure 1. Intensity Loss Scale

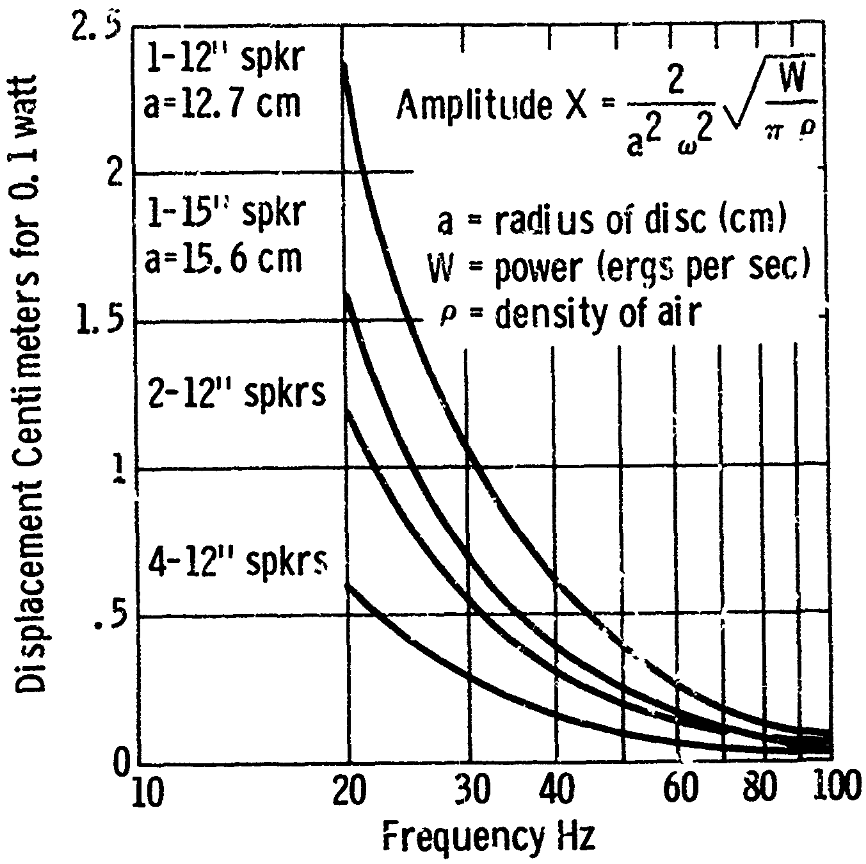

Figure 2. Displacement vs Frequency at 0.1 Watt Output

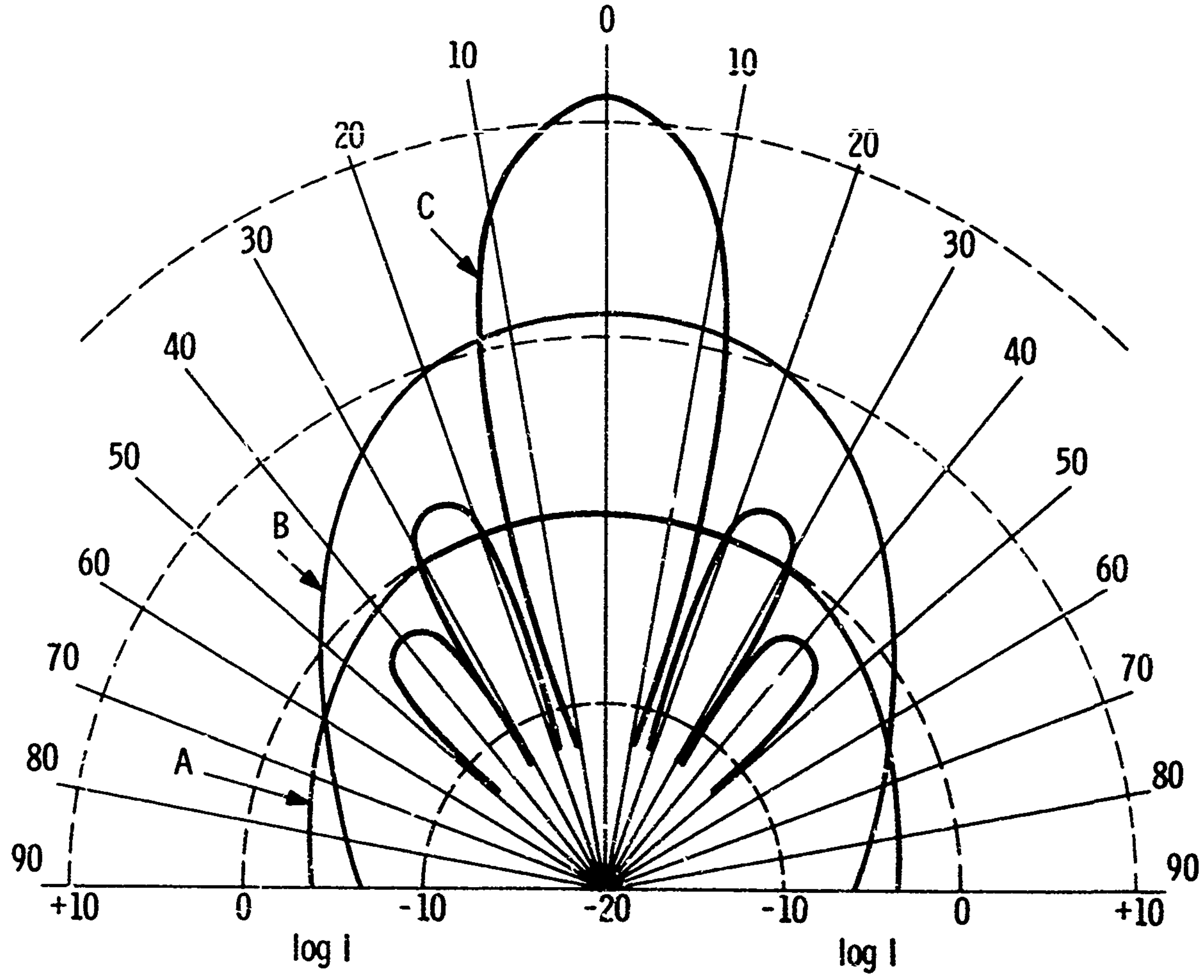

Figure 3. Polar Radiation Patterns of a Flat Piston
(Log I is plotted against θ for (A) $\lambda = 4d$, (B) $\lambda = d$, and (C) $\lambda = d/4$)

A three-way columnar system, shown in figure 4, provides columnar arrays of the remaining three other diameter speakers. The use of columnar arrays for the three upper portions of the sound reproduction system permits the use of multiple smaller cone speakers to move large quantities of air, and still maintain optimum transient response. The use of different diameter arrays assures constant directional characteristics to 15kHz over a 90-degree distribution angle. An array of six 8-inch speakers covers the spectrum from 100 to 800 Hertz. The nine 4½-inch speaker array operates in the range from 800 to 2500 Hz, and the eight 2-inch speaker array extends the range to 15kHz. This configuration, used in combination with an electronic crossover system, using 6 db/octave filters, and three 100 watt rms audio power amplifiers will produce a sound pressure level of 130 decibels at 4 feet from the system. For higher acoustical output capacity, multiple arrays of loudspeakers and additional amplifiers may be used, increasing the sound pressure level by 3 db each time the number of loudspeakers and amplifiers is doubled. A typical installation consisting of a professional grade tape reproducer, the Dolby Noise Reduction System, a three-way columnar loudspeaker system, a low frequency supplement system, three 100 watt power amplifiers, and miscellaneous accessories will cost approximately $5,500. To add another three-way columnar system, the bass supplement system, the three power amplifiers and accessory cabinetry will cost an additional $2,500 to achieve a 3 db increase in acoustical output.

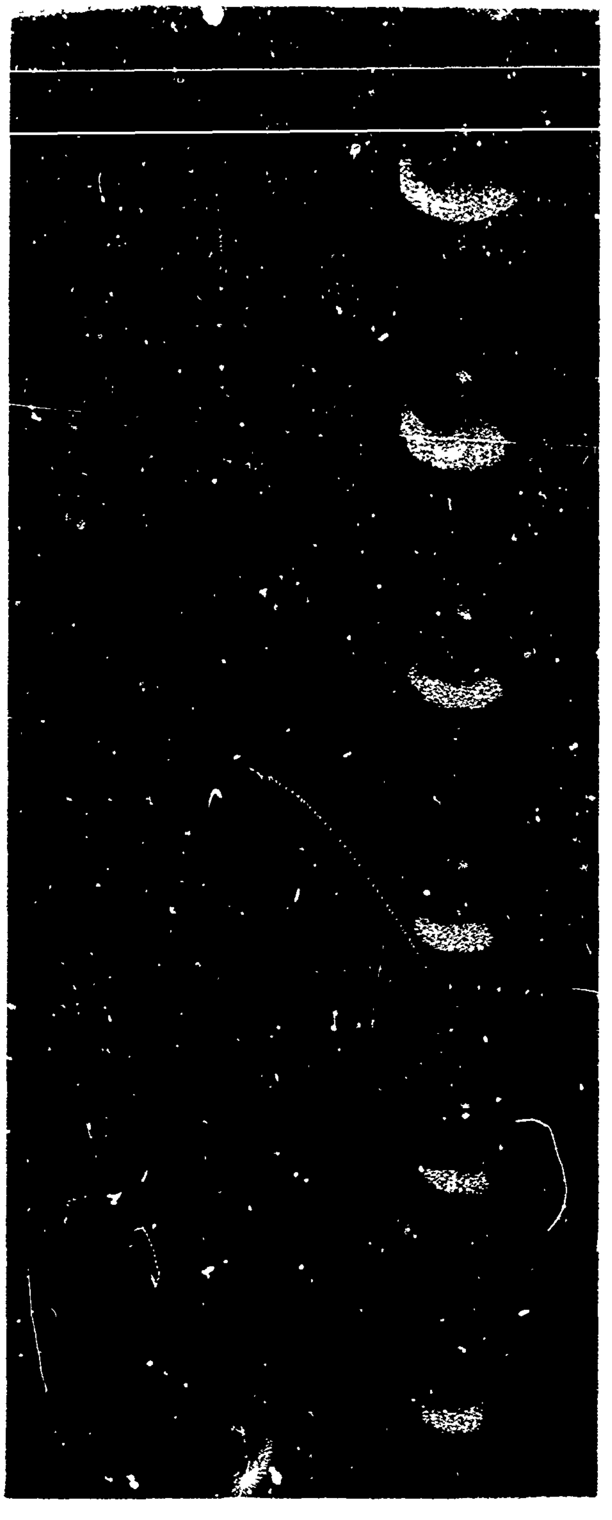

Figure 4. Photograph of the Three-Way Columnar Loudspeaker

Horn loudspeakers are noted to be a higher efficiency than cone units. However, their 6 db increase in efficiency is wasted when horn systems must be used with the lower efficiency cone loudspeakers for reproduction of frequencies below 300 Hz.

Multiple speaker systems, which use different diameter loudspeakers for various parts of the sound spectrum, must be tied together with a common distribution system, which separates the sound spectrum into bands, and then channels the respective band to the correct loudspeaker element. This distribution system is usually a passive inductor-capacitor network configuration known as the crossover network. It is the task of the crossover network to provide a smooth transition of sound from one loudspeaker mechanism to the one in the adjacent band. The topic of crossover network action is complex enough to be a study in itself, but for this discussion, it is sufficient to say that the connection of the crossover network's inductor in series with the low frequency loudspeaker causes a restriction on the transient response of the low frequency speaker, and the ability of the power amplifier to provide proper damping action. A typical effect of this series inductor is to cause the low frequency loudspeaker to produce a ringing characteristic, when activated by a sharp pulse signal. A significant improvement in optimizing loudspeaker transient response is through the use of electronic crossover networks and multiple power amplifiers. The electronic crossover network uses resistor-capacitor filter networks with buffer amplifiers to separate the sound spectrum into the required bands. A separate audio power amplifier is then used for each band's amplification, with the respective loudspeaker connected directly to the amplifier without any series elements to destroy transient response. The electronic crossover concept offers further advantages in lower intermodulation distortion, lower overload distortion, better transient response, and higher peak power output capacity. The Marine Corps Education Center at Quantico, Virginia is currently using a pair of three-way columnar loudspeakers with electronic crossover networks, and multiple 80-watt power amplifiers to provide an indoor combat sound reproduction system for use in amphibious assault training at Ellis Hall.

CONCLUSION

This paper has described some of the effort to date on behalf of the development of combat sound reproduction systems. A detailed study of the peak sound pressure level, produced by various combat weapons as well as waveform and spectrum analysis is needed to provide the information necessary for further investigation of combat sound reproduction systems. Perhaps the development of new mechanisms for transducing electronic signals into acoustical energy is required. There is much work to be done in the area of combat sound recording and reproduction and it is hoped that electroacoustic simulators capable of generating peak signals of 180 decibels will soon be found.

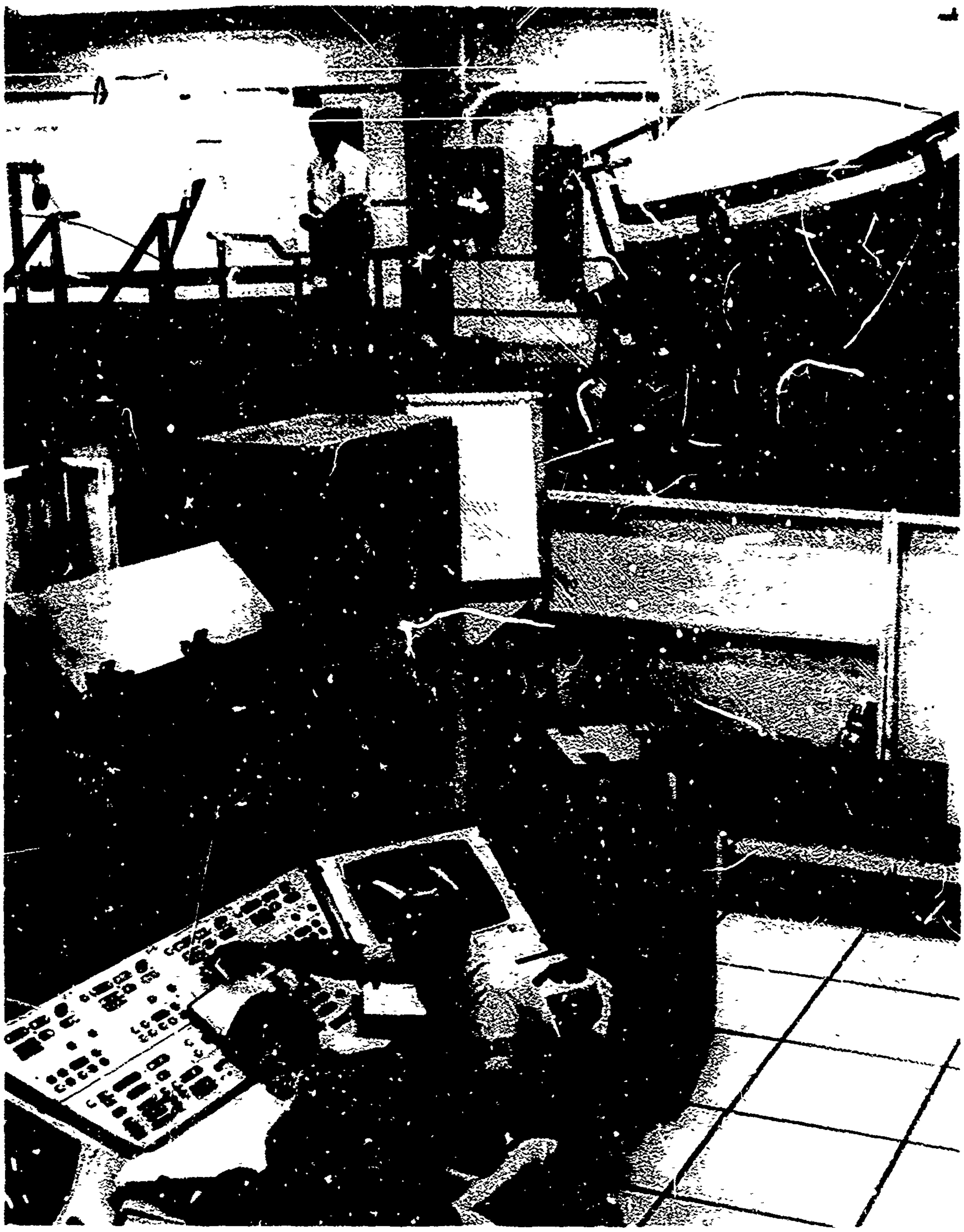

Figure 1. Ground Training Devices for Pilot Training

APPLICATION OF ADVANCED SIMULATION TECHNOLOGY TO PILOT TRAINING

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INTRODUCTION

For many years flight crew training followed a very traditional pattern; pilots were required to practice maneuvers in an aircraft for the purpose of developing skill levels sufficient to pass a rating check. Each new training program was modeled after those preceding; changes were minimal.

Later, as a result of the ingenuity of personnel concerned with training problems, the use of ground training devices was introduced into pilot training programs. These trainers were first used for instrument flight training and later for procedures training. After several evolutions of ground-based trainers, each possessing increased training capability, managers of pilot training programs became increasingly aware that simulators provide a suitable training environment and achieve many training objectives in a more efficient manner and with greater safety than the aircraft they simulate. At the present time, flight simulators have progressed to a point where airline training center managers foresee using little or no aircraft time in upgrading pilots to new equipment qualification.

Even with increased emphasis on the use of ground training devices little attention was given to the role of the instructor. Simulator flight instructors were also burdened with such tasks as problem control and simulator operation, and thus were too overburdened to apply their instructional talents effectively. The result was less than maximum effectiveness in the use of modern ground training devices.

With the advanced digital computers and programming techniques now available, solutions to these instructor problems exist. Automated instructor aids such as problem initialization, malfunction insertion, and objective performance evaluation can relieve the instructor of much of his auxiliary workload, allowing him to assume his unique role as a manager of training.

AUTOMATED TRAINING FEATURES

Following is a discussion of some advanced training techniques that have been devised for use with modern pilot training in flight simulator complexes (the order in which the items are listed is irrelevant).

1. Rapid Initialization. Many years of pilot training have produced a general sequence for teaching flying. Generally, flight training begins with the instructor flying the aircraft to a safe altitude, and then allowing a student to examine the effect of control movements. Simple, basic maneuvers such as straight and level flight, medium turns, climbs, and descents are then practiced. These are followed by maneuvers of increasing complexity until the entire syllabus has been presented. This sequence of learning has proven successful and necessary only, when aircraft are used and, when safety of flight is paramount. However, since these first-learned basic maneuvers are required in all later flights, a considerable amount of expensive aircraft time is necessarily consumed in repeating these maneuvers for other than learning requirements. This is true for both instrument and contact flight activities in either beginning flight schools or professional pilot

training. While such inefficient use of expensive hours cannot be eliminated, when using aircraft, it can be eliminated when using simulators. Rapid initialization allows the instructor (or student) to quickly select a preprogrammed position and simulator configuration without flying to that position. The result is restricting practice to the desired training objectives, greater utilization of simulator, trainee and instructor time, and a significant reduction in costs. With the use of currently available computers, the number of preprogrammed starting points and configurations are almost unlimited.

2. Automated Demonstrations. Another technique commonly used in flight instruction is the demonstration of a maneuver by an instructor after which the student is permitted to practice the same maneuver. The demonstration of these maneuvers varies not only from instructor to instructor but also from trial to trial; this inconsistency provides a poor model for the student. By using a high-speed computer to drive the simulator, it is possible to present a consistently perfect (or purposely erroneous) model performance which may be used again and again by all students. Any number of maneuver demonstrations may be developed. This technique frees the instructor from the aircraft flying task and allows him to concentrate on insuring that the trainee understands the basic cues and subtleties necessary to perform the maneuver. These models also permit increased efficiency in the use of the simulator for solo student training flights, and may be used effectively to standardize instructors as well as ratings of performance.

3. Automated Sequencing of Maneuvers. An extended application of the automatic demonstration mode is the capability of preprogramming a sequence of maneuvers. Since each maneuver, or mission segment, is coded for individual selection it is a simple process for an operator to either program a series of maneuvers, or to call up new ones, if student performance indicates such to be desirable.

4. Automated Malfunction Insertion. An important aspect of all pilot training, particularly in aircraft with more complex systems, is the handling of malfunctions and emergencies. While some of this training can be taught in the aircraft, it is an expensive classroom. Since many of these procedures may induce safety of flight problems, or cannot be taught in the aircraft, the use of ground trainers is required for hands-on training. An additional consideration is that the handling of malfunctions and emergencies can best be taught if no artificial cues, such as observing the actions of an instructor or engineer, are provided. The use of computer-controlled malfunction insertion provides more realistic cueing (progressively worsening if appropriate), and realistic and effective training can then be achieved.

5. Monitoring Procedural Items. Early phases of pilot training involves the learning of new procedures as well as basic perceptual-motor skills. Once the basic piloting skills are learned, more advanced flight maneuvers are performed by simply using different combinations of these skills. On the other hand, new or added equipment usually involved learning procedure sequences which differ significantly from those learned earlier.

Since these procedures are well-defined, and can be described in terms of system logic, they are readily adaptable to monitoring by the computer software associated with modern simulator complexes. For the same reason, it is relatively simple to automate a training program for student use. This capability, when used in modern simulators, serves to relieve the instructor of a significant portion of this otherwise attention-demanding and time-consuming task. This capability will also permit effective trainee practice during solo simulator missions.

6. Automated Recording of Student Performance. In pilot training, as in other learning situations, it is necessary to determine trainee progress. Since the computer, which provides the brains for integrating all simulator components, uses basic aircraft performance data and computed derivatives to make the simulator perform, these same data may be output in objective terms to describe student performance. Such data on selected parameters can be made available in real-time to assist the instructor in his complex task and later as feedback to the student. These accurate objective records reduce the instructor's recording task significantly and thus allow him additional time to observe student activities, which do not lend themselves to objective recording.

7. Automated Performance Comparison. Pilot performance in several parameters such as ability to maintain desired altitude, airspeed, heading, rates of turn, rates of descent, and coordination are particularly adaptable to recording as described in (6). Once these data are provided, it is then a relatively simple matter to program the computer to compare these data with predetermined criteria, and to provide an immediate readout or printout of how student performance compares with predetermined criteria. Such records are extremely valuable in supplementing the instructor's overall evaluation.

8. Knowledge of Results. The annals of research literature, in the field of learning, are filled with studies which indicate that immediate feedback of information on the quality of trainee performance proves valuable in accelerating student learning. The capability of recording performance (6) allows the development of techniques for presenting the student with a comparison between his performance and some selected standard. The use of data, as discussed in (7), provides him with pass-fail data; however, at the start of training, it may prove more valuable to set the standards at a lower level and increase these standards with student progression, using these readouts as a method of "rewarding" student effort. Such manipulations can be easily executed, either manually or automatically, and the data presented in terms of digital readouts or some other means of information transmittal.

9. Adaptive Training. Considerable research has been conducted which indicates that learning of perceptual motor skills can be accelerated by varying task difficulty in a controlled, orderly way. This theory suggests that a motor skills task can be learned more quickly if made easier by some means until the skill is learned, and then increasing the difficulty level as performance improves until final criterion performance is achieved. One term for this is adaptive training. The computer capability of current and projected simulator complexes provides a means of using this training technique. However, there are differences of opinion among experts as to whether the changes in difficulty should be based strictly on student performance or whether a stepped increase in difficulty, based on time or trials, should be used. (Where good performance is rewarded by increasing the task difficulty, this is not necessarily a reward in the trainee's mind.) In either case, the simulator computer can provide this capability.

10. Self Confrontation (Playback). A final training feature, which is possible as a result of the computer capabilities discussed earlier, is recording a trainee's performance which can later be replayed. This feature allows the student and instructor to observe and analyze trainee performance in a relaxed atmosphere wherein the student is not distracted by performance requirements. A freeze and slow replay capability, such as currently used in sports television productions, as well as a fast forward selection mode, is also provided. This capability should be extremely valuable for increasing the effec-

tiveness of debriefings. However, the question, not yet answered, is whether or not such a feature is as valuable as additional real-time trials; since the playback, as now conceived, will require simulator time. Additional research is needed.

OTHER ADVANCED INSTRUCTION CAPABILITIES

The ten features discussed above reflect the use of digital computers to automate various training systems. There are two other simulator developments that promise to provide better instruction, and deserve mention. The first is the use of cathode ray tube (CRT) display systems to present data to instructors. In recent years, the combination of increased computer capability and reduced CRT costs has led to the use of CRT displays as instructional aids. Such systems are in use for presenting automated performance readouts to trainees; for presenting instrument readouts, check lists, and repeater visual displays at instructor stations; and for providing information to training observers and maintenance personnel. They have proven extremely versatile and effective and, since the information displayed may be computer-stored and recalled as needed, they also permit a savings in space that otherwise would be needed at the instructor's console. While performance records presented on CRT's are temporary, permanent records can be made by photography or electrostatic techniques.

CRT's should also be extremely useful in presenting animated or filmed maneuver descriptions. Recent developments suggest that a 3-dimensional picture can be presented, which may prove valuable for some applications, when displaying maneuver patterns.

A second instructional aid associated with computer utilization is the capability to provide automated audio briefings. With proper software application, it is possible to present a standard briefing to all trainees and recall all or a portion of these briefings for individualized instruction.

The preceding are some of the more significant capabilities that have recently become possible, but have not yet been fully exploited.

SPECIFIC APPLICATION

The features discussed include some which have recently come into general application with advanced simulator complexes, and some which are ideas that are feasible, but need to be validated in a pilot training system. For example, two years ago Link Division of the Singer Company, and the TransWorld Airline Training Center completed a joint experimental program for recording trainee performance. Software was developed for automatically recording all significant parameters (and other parameters considered interesting but not critical to performance) on three of the 12 maneuvers required for upgrading pilots to a new aircraft. Programmed comparisons and error scores were output. The results indicated that such programs were feasible, workable, and useful.

In a more recent project, Link delivered to the United States Armed Forces a "Synthetic Flight Training System" (SFTS) for use at the U.S. Army Aviation School.

The SFTS was designed for the Army's helicopter training program. It is a flight simulator that is a "generation" in advance of any current simulator in use for commercial or military training. Simulators other than the SFTS

are basically instructor-controlled devices; i.e., the instructor sets-up the training problem and the flight environment being simulated and monitors the trainee, while he practices to develop the required skills.

In the SFTS, the computer rather than instructor can be made responsible for:

1. Selecting the flight problem - what the trainee will do in a particular training session,

2. briefing the trainee on the training problem to be executed,

3. demonstrating the ideal performance to the trainee,

4. scoring and evaluating trainee's performance against objective standards, and,

5. providing feedback to the trainee concerning his performance.

The SFTS incorporates the latest developments in automated training techniques and digital computer technology and performs the above listed functions efficiently and objectively. The automated training features also make possible adaptive training, whereby task difficulty is modified by manipulating selected variables, and making incremental additions and deletions of control inputs, and/or helicopter stability augmentation.

Like existing simulators, the SFTS also provides high fidelity simulation of motion cues, aural cues, cockpit instrumentation, and cockpit controls to provide a realistic environment for the training of pilot tasks. When fully implemented, it is anticipated that the SFTS will substantially reduce flying time in the Army's helicopter training program.

SUMMARY

Modern ground-based flight simulators have evolved, in part, from rapid development of increased computer capabilities. These same computer capabilities can, by innovative software development, be used to reduce the workload of the simulator instructor. Some of the major areas in which assistance can be provided are: (1) Rapid initialization for specific maneuvers; (2) automated demonstrations; (3) preprograming of a sequence of maneuvers; (4) automated malfunction insertion; (5) automated monitoring of procedural items; (6) recording of student performance; (7) automated performance comparisons; (8) providing knowledge of results; (9) adaptive training; and (10) providing a recording and playback capability for later study. In addition, other equipment capabilities have been developed for evaluation as to their application in a simulator pilot training complex. These include increased use of CRT display systems and automated briefings.

All of the features discussed are aimed at reducing the load of the instructor, thereby allowing him more time to function in the role of a manager of training and permitting him to concentrate on parameters which can only be handled by subjective evaluation. Such remaining activities are: (1) Diagnosis of problem areas resulting from a lack of student understanding; (2) identification of trends of incorrect performance across the total training spectrum; (3) identification of judgmental errors; and, (4) development of decision-making ability.

The combination of all the special training features, and the increased capability of the instructor to concentrate on required subjective evaluation areas, will result in maximizing the training value and efficiency of the simulator complex, thereby insuring a most cost-effective training program.

SIMPLIFYING DYNAMIC VISUAL DETECTION SIMULATIONS

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As part of a larger program at Cornell Aeronautical Laboratory, Inc. (CAL), it became necessary to use empirical data for the validation of a mathematical visual detection model, but more importantly to gain insight into the nature of visual detection of aircraft having a fragmented variation in brightness. The study of structured targets is of great interest because their detection cannot be validly derived by considering them to be equivalent to an unstructured target with uniform brightness equal to the average brightness of the structured target. Particular attention was paid to glint (specular reflection of the sun) and to brightness patterns caused by shadows cast by aircraft structures. Specifically, we were studying the detection of aircraft by ground observers. The required data were the instantaneous probabilities of visual detection of the aircraft at every point along its flight path.

In our search for such data, we found that previously reported laboratory studies used unpatterned (or unstructured) targets while field studies, using real aircraft, generally had poor documentation of the brightness variations of the target and the sky background. Hence, it was decided that a very basic experimental effort was needed. Essentially it consisted of the acquisition of data in the laboratory using human observers and simulated aircraft; and the subsequent use of the data to make quantitative comparisons within two families of structured targets with arbitrarily chosen parameters and to spot check the predictions obtained for the CAL visual detection model for unstructured targets.

Three possible experimental techniques were initially considered. They were: (1) Full-scale field tests using real aircraft; (2) scale-model field tests; and (3) laboratory tests. Considerations of both time and cost constraints, and experimental efficiency and controllability, required that the tests should be carried out in the laboratory. A technique was developed which did not require the presentation of moving stimuli, but rather required only the presentation of static targets for some length of time. The use of non-moving targets is predicated on the assumption that movement detection effects can be ignored since the range of the simulated aircraft is great at the time of detection.

The technique was based on a mathematical approach which requires as input, the average length of time spent in search to detect a target of a given size at each of several ranges, a search time limit, the number of times the target was detected within the search time limit, and the number of times the target was missed (search time limit was exceeded without detection).

From these data, the cumulative probability of detection may be calculated on the basis of an hypothesized target path and speed. The experimental methods used in this study bear a strong resemblance to one carried out by Krendel and Wodinsky in 1960, who simulated targets, by spots of light projected onto the dome in a planetarium (reference 2).

Rather than resort to slide projection of targets onto a standard projection screen in the present study, a large background screen was constructed against which physical targets could be presented. This provided several advantages over slide projection including: (a) A greatly increased field-of-view; (b) an increased viewing distance that allowed five observers to be tested simultaneously,(c) a greater range of brightness than could be provided with a photographic slide projector;(d) much higher screen brightness (this decreases the contribution of peripheral vision, relative to foveal vision, to a level closer to that for daylight brightness, and brings the brightness into the range where the brightness difference threshold ratio is independent of brightness); e) no "noise" as might be introduced by dust or scratches within the projector or on the film; and, f) relative ease of creating structured target locations.

METHOD. The procedure used in this experiment was the presentation of static targets, one at a time, on a relatively large background screen. Each target was exposed for thirty seconds, during which time the observers searched the background, with the goal of detecting the target in the shortest possible time. The targets varied in size, contrast, configuration, and location on the background. The experiment was conducted in the auditorium of the Cornell Aeronautical Laboratory. Heavy curtains on all windows provided control over ambient illumination.

BACKGROUND SCREEN. A vertical screen 8 feet high by 28 feet long, was constructed and located at one end of the auditorium. It was composed of seven 4x8 feet plywood sheets, each covered with a piece of 3/4-inch thick gray polyester foam. The shade of the foam allowed the targets to be composed of areas which were less reflective (darker) than the background as well as areas which were much more reflective (lighter) than the background. It was anticipated that each piece of foam would be uniform in color so that when the panels were juxtaposed they would appear as a single, seamless screen. In actuality, the edges of the pieces had nonuniformities which made it impossible to obliterate the dividing edges. The nonuniformities and the dividing edges were avoided in the selection of target locations. Three of the foam pieces differed by about 10% from the other four when their brightnesses were measured under the normal fluorescent room lighting. The screen may be seen in the background of figure 1.

ILLUMINATION. Although the brightness of the sky varies widely in magnitude, it is not practical to reproduce daylight brightness in the laboratory. It was possible, however, to provide sufficient illumination to insure that the background brightness was in the region where the brightness difference threshold ratio is equal to a constant. This illumination was provided by twelve 1000 watt lamps (G.E. Catalogue No. Q1000 PAR 64/7) placed 6 inches from the floor and about 20 feet from the screen. They provided a screen brightness that varied between 39.1 and 56.8 foot-lamberts over the screen. All brightness measurements were made with a Spectra Pritchard photometer. A panel covered with black cloth was placed at each side of the screen to absorb the illumination spillover from the lamps. A low barrier, also covered with black cloth, was placed between the lamps and the observers in such a position that the observers could see neither the lamps nor the floor between the lamps and the screen.

OBSERVERS' STATIONS. Five observers participated in the experiment simultaneously. Six barriers were arranged so that the five observers could sit in a row, facing the screen, without being able to see each other or the experimenters. Each station was 3 feet wide resulting in a distance of 6 feet between the midline of each end observer to the midline of the center observer.

During every observation period, each observer rested his head on a post 42.5 inches high, to insure that the eye height was uniform among subjects. Each of these head rests was located 50 feet from the screen. A curtain was hung across the front of the barriers which could be lowered between trials to prevent the observers from seeing the placement of the targets. With the curtain in the raised position, the observers could not see the area about the screen. The observers stations are shown in figures 1 and 2.

Figure 1. Experimental Arrangement Looking Toward the Screen

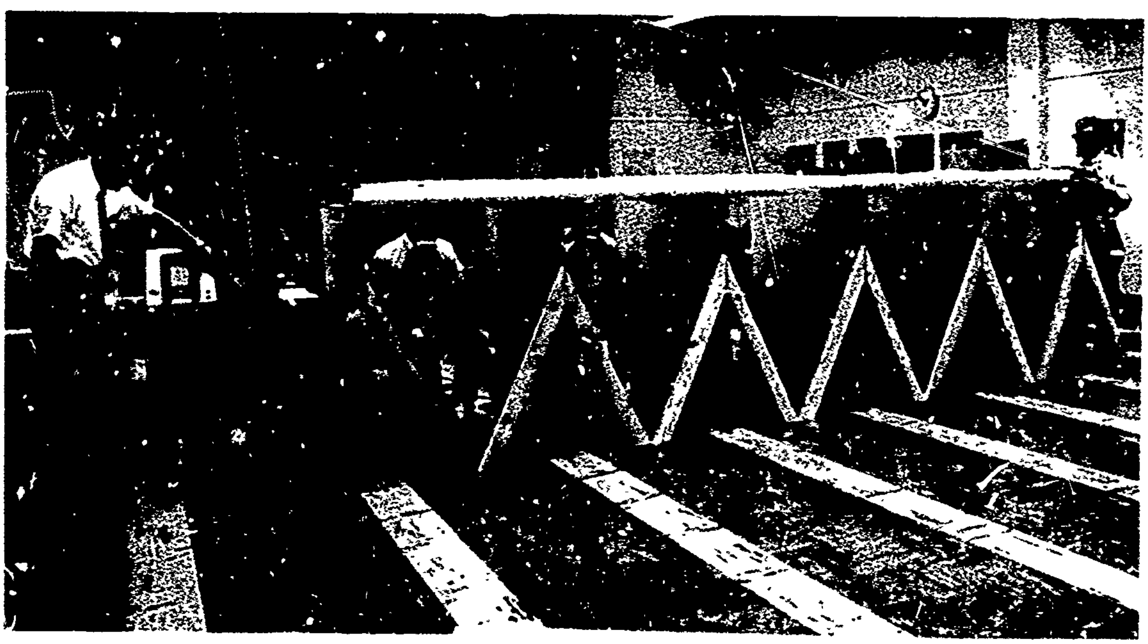


Figure 2. Experimental Arrangement Looking Toward the Observers

DATA RECORDING. Each observer held a push button switch which when pressed would activate a channel of a Brush 30-channel Operations Monitor (event recorder). A Gralab Universal Timer was connected, by way of a relay, to activate a sixth channel of the recorder whenever the timer was in operation. Each observer had a supply of scoring sheets on which was a line drawing of the screen, as shown in figure 3. The observers used these sheets to indicate the location of the target for each trial.

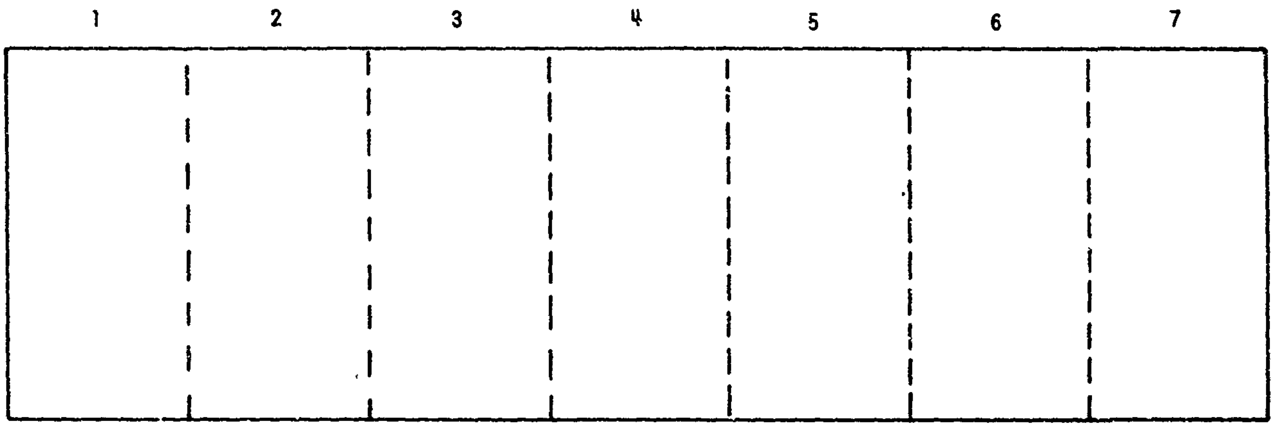


Figure 3. Sample Score Sheet used by Subjects to Indicate the Location of the Target

TARGETS. Six target configurations were used in the two studies performed; three were of uniform contrast, and three were structured. All targets consisted of, or were derived from, cut-out circles of varying shades of gray art paper. These papers were chosen for their matte surface as well as their particular contrasts with respect to the foam background. The papers were numbers G15 and 204 (Craftint Colormatch) and number Gray 8 (Color-aid). A piece of "double-stick" tape was attached to each target making it possible for the targets to be attached to the foam background and yet be easily removed by touching only the edges. Because of their thinness, the targets cast no shadows.

Contrasts of the three papers with respect to the background (as defined by $B_T - B_b / B_b$, where B_T = brightness of the target and B_b = brightness of the background) were measured for a variety of locations on the background and from the positions of various observers. For paper 204, the contrast varied between -0.47 and -0.56 with an average value of -0.51. For G15, the contrast variation was somewhat larger, ranging between +0.31 and +0.50, with an average value of +0.41. Paper number 8 also had a higher range of contrasts, varying between -0.10 and -0.23 with an average of -0.14. The contrast variability increased with increasing contrast. In one configuration to simulate glint, white spots were added to the targets. The spots were painted on the number 204 paper using Liquid Paper typing correction fluid which, was measured to be 11.5 times more reflecting than the foam background, and has excellent diffusing properties.

Figure 4 illustrates the basic configurations. The details of the six target configurations are given as follows:

1. Uniform contrast (-0.51). Circular targets were cut from paper number 204. Figure 4(a).

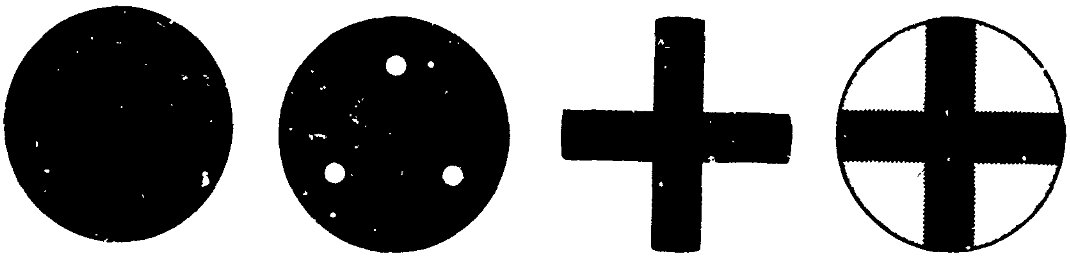
2. Uniform contrast (-0.14). Circular targets were cut from paper number 8. Figure 4(a).

3. Uniform contrast (+0.41). Circular targets were cut from paper number G15. Figure 4(a).

4. Glint. Targets of the first configuration were altered by adding three white spots. The diameter of each spot was 0.122 times the diameter of the target so that the average brightness of the target was equal to the brightness of the background (an average contrast of zero). As shown in figure 4(b), the spots were arranged in an equilateral triangle with the distance between the spot and the center of the target equal to two-thirds of the radius.

5. Structured (unbalanced). Targets of the first configuration (Figure 4(a)) were altered by cutting wedges from them leaving x-shaped targets (Figure 4(c)). The width of the bars equals 0.22 times the diameter of the circle from which it was cut. This results in the remaining area of the target equaling one-half of the original area of the circle, thus reducing the average contrast to -0.25. This target is illustrated in figure 4(c).

6. Structured (balanced). Targets as in figure 4(c) were attached to circles of equal diameter cut from paper number G15 (figure 4(d)). It had been anticipated that paper G15 would yield an average contrast of +0.5 so that the lighter areas of this target would exactly balance the darker areas for an average brightness equal to the foam (average contrast equal to zero). However, with the actual value of +0.41 for paper G15, the resultant average contrast was -0.05.



a b c d

Figure 4. Basic Configurations: (a) Uniform Contrast Target; (b) Glint Target with Three Compensating Spots of Combined Area Equal To Five Percent of the Background Area; (c) Structured (Unbalanced) with One-Half the Area Removed; (d) Structured (Balanced) with One-Half the Area Compensating the Remainder

Each target configuration was presented to the observers in five different sizes. The sizes were selected on the basis of preliminary observations so that the largest sizes would be easily detected, while the smallest sizes would be nearly undetectable using foveal vision. This selection resulted in a different set of sizes for each target configuration. Table 1 lists the actual target size, as well as their angular visual subtense.

Subjects. Five male employees of CAL were selected from volunteers on the basis of having no worse than 20/20 vision as measured with a standard eye chart (Snellen) without correction. As far as can be determined, they were uninformed with respect to the hypotheses being tested, but probably were familiar with the general program.

TABLE 1. TARGET DIMENSIONS

CONFIGURATION	SIZE (DIAMETER)									
	LINEAR (IN mm)					VISUAL SUBTENSE (IN MINUTES) AT A DISTANCE OF 50 ft				
	1	2	3	4	5	1	2	3	4	5
UNIFORM (-0.51)	5	8	9.5	15	25	1.13	1.80	2.14	3.38	5.64
UNIFORM (-0.14)	20	25	30	35	40	4.51	5.64	6.76	7.89	9.02
UNIFORM (+0.41)	5	8	15	25	35	1.13	1.80	3.38	5.64	7.89
GLINT	9.5	15	20	30	35	2.14	3.38	4.51	6.76	7.89
STRUCTURED (UNBALANCED)	9.5	15	20	25	35	2.14	3.38	4.51	5.64	7.89
STRUCTURED (BALANCED)	15	20	25	30	35	3.38	4.51	5.64	6.76	7.89

Procedure. Each trial consisted of thirty-second search period followed by another thirty seconds during which the observers' reports were gathered, and the next trial was prepared. Three experimenters were required to conduct the study.

The initial preparation consisted of the following steps and instructions:

1. The observers were familiarized with the general nature of the study.

2. The observers adjusted the heights of their chairs so that they could comfortably place their chins on their headrests.

3. The screen was exposed so that the subjects could familiarize themselves with its nonuniformities. The areas where targets would not appear (discussed below) were pointed out.

4. The set of targets to be used in a phase of testing were shown to the observers before the beginning of each phase. The targets were attached to the background and each was pointed out in turn.

5. The observers were informed that the targets would appear randomly (in position, size, and configuration) and that in approximately one-ninth of the trials no target would be used.

6. Observers were encouraged to search in as nearly a random fashion as possible; that is, they were to try to not systematically search in a fixed pattern.

7. In order to maximize correct responses and minimize false alarms, the observers were awarded points according to a payoff matrix in which correct responses (hits and correct rejections) were given one point, while wrong responses (misses and false alarms) were given zero points. The observers were informed that prizes of value from $10 to $2.50 would be awarded on the basis of total score, weighted by their average time to make a response.

Before the curtain was raised to commence a trial, a ready signal was given, at which time the observers were to take hold of their pushbutton switches and position their heads on the headrests. As the curtain was raised, the timer was activated which began a trace on the event recorder. As soon as each observer detected a target, he pressed his switch (for at least three

seconds), which indicated his response on his channel of the recorder. If an observer did not detect a target, he was to let the time run out without pressing his switch. Immediately after indicating his detection of a target, the observer marked the position of the target on his score sheet. Second choices were forbidden. Unmarked score sheets were turned in when a target was not detected.

At the end of thirty seconds, the timer activated a buzzer and ended the timing trace on the recorder. The observers were then given immediate feedback by either pointing to the location of the target or informing them that no target was present. The curtain was then lowered. During the following half-minute, or so, the next target was placed on the background, and the score sheets were collected from each observer.

About 12 practice trials were given at the beginning of each day's session. They were chosen to constitute a random selection, but with at least one "no-target" trial.

EXPERIMENTAL DESIGN. The experiment was carried out in two phases. In Phase One, the targets used were Uniform Contrast (-0.51), Glint, Structured (unbalanced), and Structured (balanced). A complete sequence of trials was carried out on day 1. On day 2, the same targets were employed, but in a partially counterbalanced (as described below) sequence. In Phase Two, only the uniform targets (-0.51, -0.14, +0.41) were used. The Phase Two sequence was carried out on day 3 (a second sequence was not conducted).

In Phase One, there were 20 combinations of target configuration and target size. For purposes of assigning locations, the background was conceptually divided into three areas (right, center, and left) and then into four horizontal strips, for a total of 12 strips. Figure 5 shows the dimensions and positions of the strips. It may be noted that the left, right, and top borders were not used for target placement. This resulted in a search field 28° high and 8° wide. The strips were further subdivided horizontally and vertically to achieve a fairly uniform distribution of target locations.

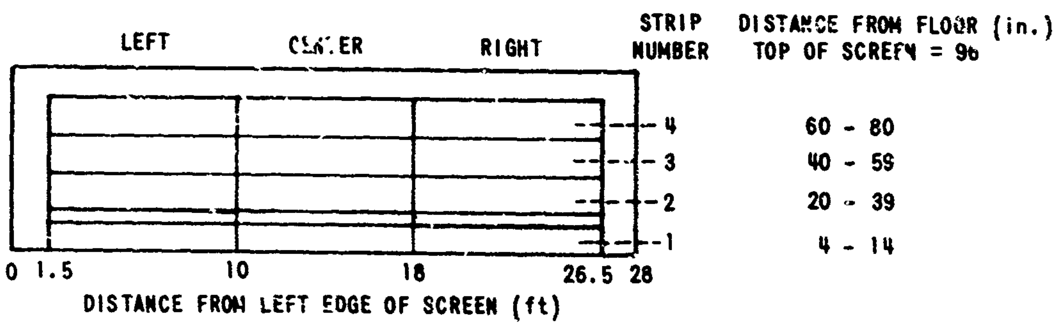


Figure 5. Dimensions and Locations of Screen Subdivisions

Horizontally the areas were marked off at one-foot intervals. Vertically each strip was subdivided into three positions for a total of twelve possible vertical positions. The height of the bottom strips was reduced in order to keep all targets presented there close to the bottom border of the background (hence the unused space between the first and second strips). This was done in order to look for possible effects caused by the presence of a "horizon."

All combinations of target size and configuration appeared once in each of the 12 area by strip (3x4) combinations. This required 240 trials (20x12). An additional 30 trials were randomly interspersed in which no targets were presented. On day 2, the sequence was run in reverse and with a partial mirror image of target locations.

A similar design was used in Phase Two, however, only 180 trials with targets were required since the number of target configurations was reduced to three (3x5) x (3x4). After the addition of 23 no-target trials, the total for Phase Two was 203 trials.

RESULTS AND DISCUSSION

FALSE ALARM AND HIT RATES. Table 2 gives the number of incorrect detections (false alarms) for each subject and for each day of testing including those trials in which a target was present. It may be seen that this type of error was very infrequent during Phase One (days 1 and 2), being less than 1 percent of the total possible false alarms. The false alarm rate increased to over 2 percent during Phase Two. This increase may be attributed to the use of more difficult targets. Almost one-half of these errors were made by observer 2. Considering only those trials in which no target was present, the average false alarm rate for Phase One was 1.7 percent and for Phase Two was 3.5 percent.

TABLE 2. FALSE ALARM AND HIT RATES

FALSE ALARMS (DETECTION OF A TARGET THAT DOES NOT EXIST)

		SUBJECT							
		1	2	3	4	5	AVERAGE	MAXIMUM POSSIBLE	FALSE ALARM RATE (%)
PHASE 1	DAY 1	0	5	1	1	2	1.8	270	0.7
	DAY 2	0	3	1	0	2	1.2	270	0.4
PHASE 2	DAY 3	3	9	4	4	3	4.6	230	2.3
AVERAGE		1	5.7	2	1.7	2.3			

HITS (DETECTION OF A TARGET WHEN IT IS PRESENT)

		SUBJECT							
		1	2	3	4	5	AVERAGE	MAXIMUM POSSIBLE	HIT RATE (%)
PHASE 1	DAY 1	198	201	217	207	174	199	240	83
	DAY 2	202	203	209	211	184	202	240	84
PHASE 2	DAY 3	130	133	140	139	128	134	180	74
AVERAGE		177	179	189	186	162			

The hit rates (correct detections) are also presented in table 2. As with the false alarm rate, the hit performance was similar on both days of Phase One; the greater difficulty of Phase Two was reflected in the lower hit rate for that data.

These results indicate the high reliability of the data, and that the nonhomogeneities in the screen (e.g., the edges of the panels) did not significantly contribute to the detection process. The latter is shown by the very low false alarm rate.

DETECTION PROBABILITY PER UNIT TIME (D) AS A FUNCTION OF TARGET SUBTENSE ANGLE (α). Figures 6 and 7 show the relation between D and α. D is a quantity defined so that the product of D and the average glimpse time is equal to the average single glimpse detection probability (see appendix). Alpha (α) is the diameter of the target in minutes. The data in figure 6 are combined in the following way:

1. The curve for the Uniform (-0.51) target series is the average of the two sets of runs (day 1 and day 2) from Phase One and the Phase Two data for the target.

2. The curves for the Structured (unbalanced), Structured (balanced), and Glint target are averaged for days 1 and 2 of Phase One.

The data in figure 7 include:

1. The average curves for Uniform (-0.51) taken from figure 6.

2. The curves for Uniform (+0.41) and Uniform (-0.14) as determined by the data of Phase Two.

The datum for α = 1.13 minutes on the curve for the +0.41 contrast was excluded since the value of D was zero.

The following observations may be made from the data in figure 6:

1. Clearly, the three structured targets decrease the probability of detection as compared to the Uniform (-0.51) targets. The Structured (balanced) condition yields much lower probability of detection than the Structured (unbalanced) and the Uniform (-0.51) condition.

2. There is no overlap of data for any curve with data of any other curve, indicating that the separations between the average curves for each treatment are reliable.

3. The curves for Uniform (-0.51) and Structured (unbalanced) are essentially parallel. If target shape is ignored, the Structured (unbalanced) targets may be considered to be the same as the Uniform (-0.51) targets but with half the area for the same maximum target dimension. In that case, there should be close agreement between the curve for Uniform (-0.51) and a curve derived by reducing the subtense angle of the Structured (unbalanced) by $1/\sqrt{2}$. Although not shown here, there is excellent agreement, especially at the higher values of α, verifying the independence of detection probability from shape for low height-to-width ratios.

4. The curve for the Structured (balanced) targets indicates a definite flattening (if not a decrease) at the higher values of α. A slight flattening may also be noted at the same place in the Glint curve.

5. The Structured (balanced) condition employed in the experiment yields lower detection probabilities as compared to the Glint configuration. Only two characteristics distinguish these two configurations from each other,

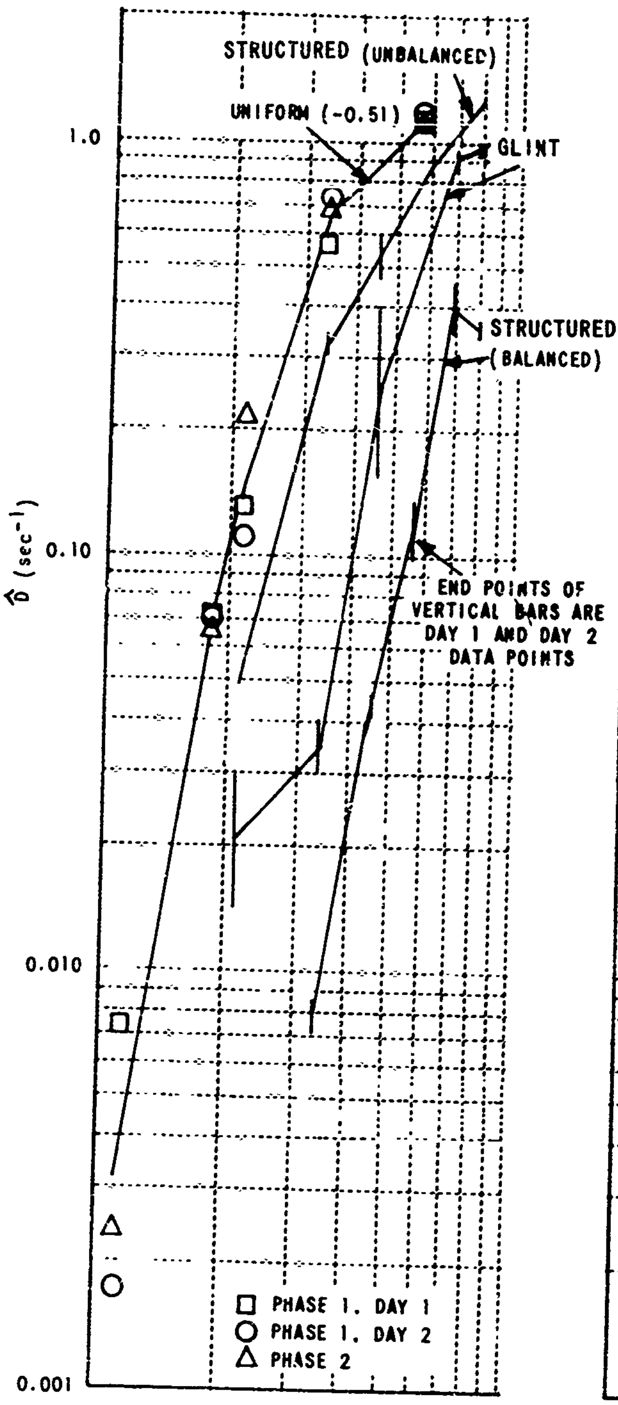


Figure 6

α (minutes)

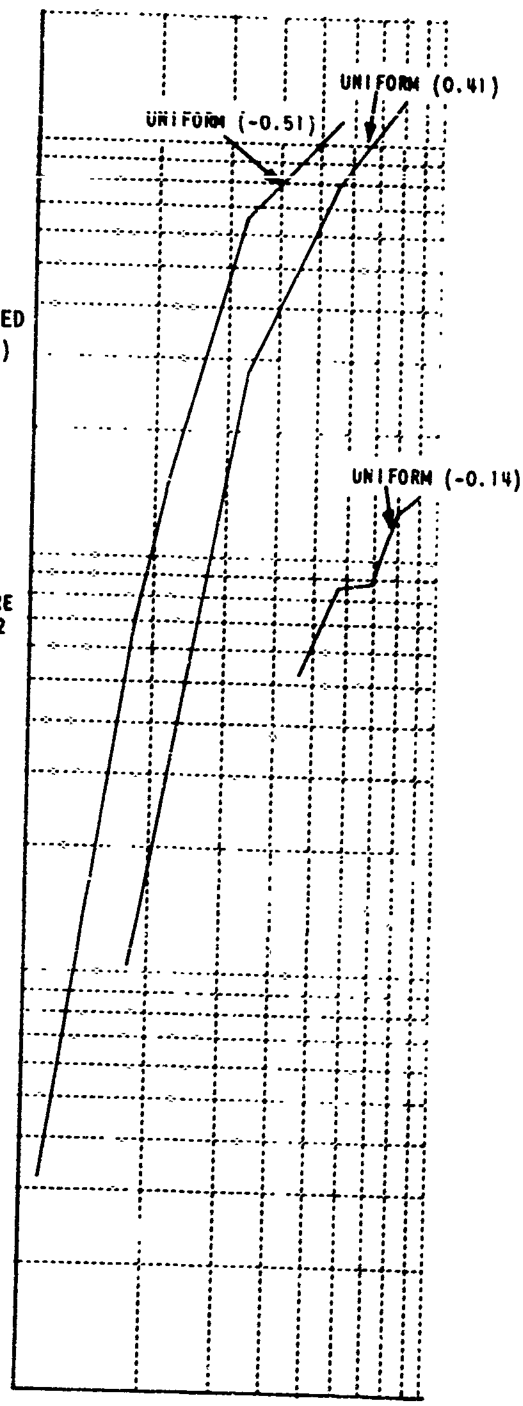


Figure 7

α (minutes)

ESTIMATE OF D ($\hat{D}$) AS A FUNCTION OF TARGET SIZE (α)

and hence, one or both of the distinctions must account for the difference in performance. Those characteristics, dealing with the internal structure (patterning) of the targets, are: (a) The brightness variation (in magnitude) within the pattern of the Glint condition was greater than in the Structured (balanced); and, (b) the spatial pattern of the Structured (balanced) was more disjoint (broken up) than was the spatial pattern of the Glint target.

The factors affecting characteristics (a) and (b) include: The number, distribution, size, and perhaps shape of the bright areas. The metrics which relate the pattern characteristics (and their interactions) to detection performance are not known. Once theoretical and experimental programs are carried out to reveal these relationships, configurations as diverse as Glint and Structured patterns may be compared along common scales. Quantitative predictions may then be made regarding the probability of detection of structured targets.

The following observations may be made from the data in figure 7:

1. As would be expected, the detectability was best for the -0.51 contrast target and similar to the +0.41 contrast target with small differences between them. The -0.14 contrast target exhibited much poorer detectability than did the higher contrast targets. It must be remembered that the actual variation in contrast varied widely around the average of -0.14. The location performance curve is therefore tenuous. Predictions based on these data should be treated with caution.

2. The curves for the contrasts of +0.41 and -0.51 are essentially parallel. The curve for the contrast of -0.14 has a near-horizontal segment at an α value which is near that for a similar flattening in figure 6.

The origin is presently unknown for the flattened segments which appear in the D versus α curves of figure 6 (Glint and Structured (balanced) in the region of 7-8 minuts of arc), and figure 7 (Uniform (-0.14) in the region of 6 minutes of arc). It is assumed that these breaks in the curves are related to visual mechanisms since no procedural errors are known which could account for the effect. Further effort is required to establish both the "reality" of these breaks, and their sensitivity to the various stimulus parameters (i.e., α , c, target internal brightness variation).

Detection as a Function of Target Location. The data were analyzed in terms of the average detection time for each target (i.e., each configuration by size combination) at each of the 12 major screen subdivisions. Targets located at the center of the screen were detected sooner than targets located elsewhere. This may come about for two reasons: (1) The average angular distance between the fixation point and the target is less for central targets than for noncentral targets; and, (2) the observers might have used a fixation sequence which favored the center of the screen.

No consistent trend was found in the detection times to support the hypothesis that targets were most difficult to detect when presented at the "horizon." Experiments can and should be more specifically designed to further test this hypothesis.

Measured Search Behavior. Following the end of Phase Two, one observer was selected for further study to examine eye movements during search. He was instructed to search for a target on the background screen while instrumented with a Biosystems Eye Movement Monitor, Model SGH/V-2 (Biometrics, Inc.). The monitor recorded the horizontal movements of the eye with an accuracy of about one-half degree. No target was actually present during search. The output was recorded on a Sanborn chart recorder.

In the trace, which lasted 57 seconds, approximately 171 saccades (shifts of gaze) occurred. The number of saccades may be slightly more or less since movements, which were essentially vertical, produced only small horizontal signals. Consequently, those judgments were difficult to make. The result of the measurement was that on the average, the point of fixation was changed three times per second.

Furthermore, it was found that this observer began his search by quickly scanning the entire background screen. In the first 4.5 seconds, he scanned the full width four times. The full-field scans then slowed (more fixations per scan) to about three to four seconds. At about the twentieth second, he began a scan of the field which took 14 seconds to complete. After this, his scanning behavior seemed to duplicate his previous pattens (very fast scans, slowing to five seconds for the last scan of the entire field). This observer's search behavior was certainly not random, but neither was it following a rigorous pattern.

The most important finding of this search behavior study was that the glimpse time was measured to be one-third second. It is unlikely that the glimpse rate for the other four observers deviated significantly from this value, since previous laboratory results (Reference 3) have also reported a value of one-third second for the average glimpse time.

CONCLUDING STATEMENT

This analysis has dealt with the probability of detection for a single glimpse. The dynamic case (for aircraft changing in angular subtense, contrast, and position in the search field) may be calculated by use of the relationships derived in the appendix.

APPENDIX A

EXPERIMENTAL EFFORT AND MODEL RELATIONSHIPS

The purpose of this appendix is to establish the relationships between cumulative probability of detection, and the visual detection data generated within the experimental effort; i.e., to derive the probability of detection of moving aircraft from static target data. The approach philosophy is the replacement of the visual detection submodel in the present computer program with an appropriate statistical representation of the experimental data. In this way, cumulative probability of detection can be established for those target configurations in the experiment, particularly the brightness structured targets that cannot be handled by the visual detection submodel.

The material to be discussed is divided into three parts. The first part discusses a closed form expression for cumulative detection probability and relates this expression to the experimental effort; the second part establishes a statistical connection between D (probability of detection per unit time) and the detection data of the experiment, and the third part presents examples comparing data and the theoretical curve generated through use of an estimator of D obtained from the data.

Closed Form Cumulative Detection Probability and Relationships. Reference 1 has established for a continuous search a closed form expression for the cumulative probability of detection as a function of time, P(t), in terms of the instantaneous detection probability density,* D(t):

$$P(t) = 1 - e^{-\int_0^t D(t')dt'} \tag{1}$$

*Not a density in the sense of integrating to unity over the entire range of the argument t. D is a density in that it is probability per unit time, and that over a short duration τ, the detection probability would be given by $D(t)\,\tau$.

It is seen that the expression is sufficiently general to account for D varying with time during the search.

One application of Equation (1) is the computation of the cumulative detection probability of a ground observer searching for a penetrating aircraft. For this application, the time dependence of D is implicit through certain properties of the aircraft and search geometry:

$$\begin{aligned} D &= D(\alpha, C) \\ \alpha &= \alpha(t) \\ C &= C(t) \end{aligned} \tag{2}$$

where α is the apparent angular size of the aircraft and C is the apparent contrast. In the context of the present study, the apparent target contrast is considered to vary during penetration through the mechanism of contrast attenuation by the atmosphere, and the subtense angle α is determined as a function of time simply from geometry. It only remains to establish D (α,C) to apply Equation (1) to the problem of aircraft penetration.

In the experiment, the dependence of D on α and C was found by employing direct measurements of detection times for a series of specific α, C values and an appropriate data reduction procedure. With regard to the experiment, a stimulus of specific α and C was presented for search, and the times required for detection were recorded for a large number of independent trials. The connection between these times and the specific values of D for each stimulus is found by applying Equation (1) with D time-invariant during search:

$$P(t) = 1 - e^{-Dt} \tag{3}$$

where the value of D depends on α and C.

Maximum Likelihood Estimator For D. The maximum likelihood estimator is a widely used statistic and will be adopted here for the probability per unit time, D. The experimental data consists of an array of detection times for each target configuration and size. The elements of each array are replications (for a particular value of D) and can be considered independent samples of a random process. In addition to the actual detection times, there were also a number of misses within the allotted search time.

We can represent the data set by the multi-dimensional sample variable T in terms of N detection times and M misses:

$$T = \begin{cases} t_1, t_2 \ldots t_N \\ M \text{ misses} \end{cases} \quad (\text{for each target}) \tag{4}$$

By a maximum likelihood estimate we mean the most probable value of D in light of everything we know about the process. That is, we shall use for an estimate

of D the value ($\hat{D}$) that maximizes the a posteriori probability density $p(D/T)$;* the solution of:

$$\frac{\partial p(D|T)}{\partial D} = 0 \tag{5}$$

for the observed data set T.

Prior to solving Equation (5) for D, it is necessary to establish $p(D/T)$. This can be done in the following manner:

By means of Bayes' Theorem $p(D/T)$ can be expressed:

$$p(D|T) \propto p(T|D)\, p(D) \tag{6}$$

where $p(D)$ is the prior probability density of D and where the proportionality constant of Equation (6) is independent of D. Since we have no established belief prior to knowledge of the data as to the value of D, $p(D)$ is taken to be constant over the range of D within which $p(D/T)$ is active. Thus Equation (6) becomes:

$$p(D|T) \propto p(T|D) \tag{7}$$

Since the N+M components of the sample T are independent, $p(T/D)$ can be written as a product of the individual probabilities. Therefore, $p(D/T)$ can be finally expressed:

$$p(D|T) \propto \left[P(t > t_o | D)\right]^M \prod_{i=1}^{N} p(t_i | D) \tag{8}$$

where t_o is the search time limit. The probability density $p(t/D)$ is found by differentiating Equation (3) remembering that D is independent of time:

$$p(t|D) = De^{-Dt} \tag{9}$$

Integration of Equation (9) from t_o to infinity yields $P(t > t_o|D)$:

$$P(t > t_o | D) = e^{-Dt_o} \tag{10}$$

From Equations (9) and (10), Equation (8) becomes

$$p(D|T) \propto D^N e^{-D\left(\sum_{i=1}^{N} t_i + Mt_o\right)} \tag{11}$$

* The Bayesian approach to maximum likelihood. As will be seen, the local extremum given by Equation (5) is in fact the global maximum for the specific case being considered.

which can be written:

$$p(D|T) \propto D^{N} e^{-D(N\bar{t} + Mt_0)} \qquad (12)$$

where $\bar{t}$ is the average of the N detection times. Since the proportionality constant of Equation (12) is independent of D, the right-hand side of Equation (12) can be substituted directly for p (D/T) in Equation (5). Carrying out the differentiation and solving for D yields the maximum likelihood estimator:

$$\hat{D} = \frac{N}{N\bar{t} + Mt_0} \qquad (13)$$

Examples of Cumulative Detection Probability. Figure 8 shows two examples of detection data and the corresponding cumulative curve. The search was truncated at 30 seconds (t_0) after initiation. The N detection times were ordered by numerical value and assigned ordinate values progressively larger by 1/N+M. The theoretical curves represent Equation (3) with D(t) replaced by $\hat{D}$ (Equation (13)).

ACKNOWLEDGEMENT

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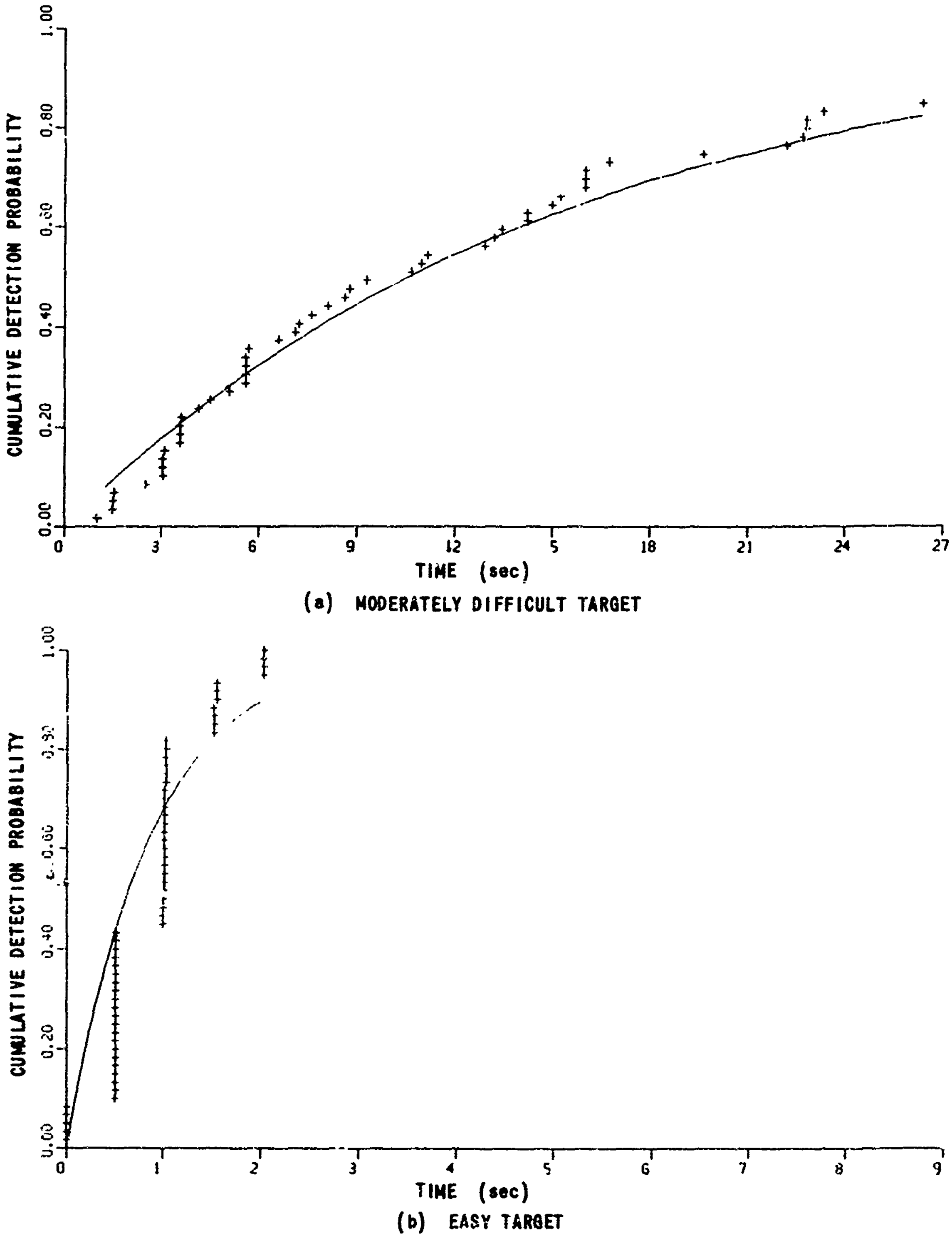

Figure 8. Examples of Data Fit to Theoretical Cumulative Probability
(Note Scale Change in Time Coordinate)

VISUAL AND MOTION EFFECTS ON AN EXPERIMENTAL WIDE-ANGLE AIRCRAFT SIMULATOR

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Visual Simulation Laboratory
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INTRODUCTION

Traditionally the piloting of an aircraft was considered essentially a visual process. This is because the eye, coupled with the computational ability of the brain, provides the human with his most powerful sensor. Although much information is available on an individual area, such as visual, much of the information on the various sensory cues are fragmentary. (Cues being defined here as information which is useful to the operator in controlling a vehicle and in making decisions as to the state of the vehicle). It was due to the prohibitive and complicated nature of combining cues that little information had been obtained on the interaction of visual and motion cues in the control of aircraft. For this reason past motion system performance and pilot's vestibular reaction to motion were not adequately defined, nor fully understood. The early trainers were limited to attempts to create realism effects such as engine induced vibration or low intensity rough air. These movements were not correlated with pilot control, nor with the visual display. Hence, false or conflicting motion cues would be introduced with resulting negative training effects. One of the objectives of continuing research would be to consider techniques which would avoid conflicting or false cues imposed by the limitation of simulation equipment. However, as described in recent Human Factor reports,[1,2], the subject of the interaction of visual and motion cues is complex and difficult. This difficulty stems partly from the limitations of the hardware, but to a great extent it stems from the complexity of the human factor elements, and lack of information on their interactions.

HUMAN FACTOR PARAMETERS

The human factor elements(6)shown in figures 1, 2 and 3 indicate the visual and motion parameters which provide the sensory information. The visual parameters are given in figure 1 starting with solid angle from the subject's eye within which cues are contained. Brightness, resolution and contrast are not considered cues, but enable cue identification. Exit pupil defines the volume of space over which the displayed image may be viewed by an observer. Range of maneuverability incorporates ground area, altitude and rotational degrees of freedom. Registration and correlation refers to control action resulting in position, rate and acceleration. It also refers to the degree of specified accuracy for training device design. The Image Distance and Depth Cues are shown to consist of monocular and binocular cues. It should be noted that except for light and shade and accommodation (which refers to eye focussing) the monocular cues are amenable to quantitative or geometrical descriptions. The binocular cues are related to near distant cues such as for helicopter landings. Special effects refers to such things as variations in weather and visibility.

Proceeding further with figure 2 we can see some of the effects of various conditions on the threshold characteristics of a cue. These illustrate the effect of variables in detecting movement on a visual scene. Here we see

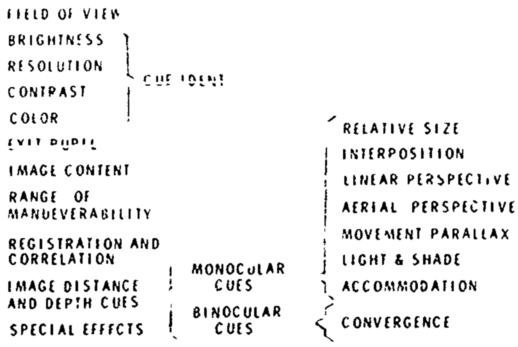


Figure 1. Visual Parameters

VARIABLE	FUNCTION	THRESHOLD EFFECT
VELOCITY	INCREASE	INCREASE
DURATION	INCREASE	DECREASE
FIELD	INCREASE	DECREASE
ILLUMINATION	INCREASE	DECREASE
RETINAL AREA	INCREASE PERIPHERY	INCREASE
ACUITY		
(MONOCULAR)	NEAR DISTANCE	INCREASE
(BINOCULAR)	NEAR DISTANCE	NO CHANGE

Figure 2. Variable Conditions Influencing Threshold Values for Discrimination of Movement

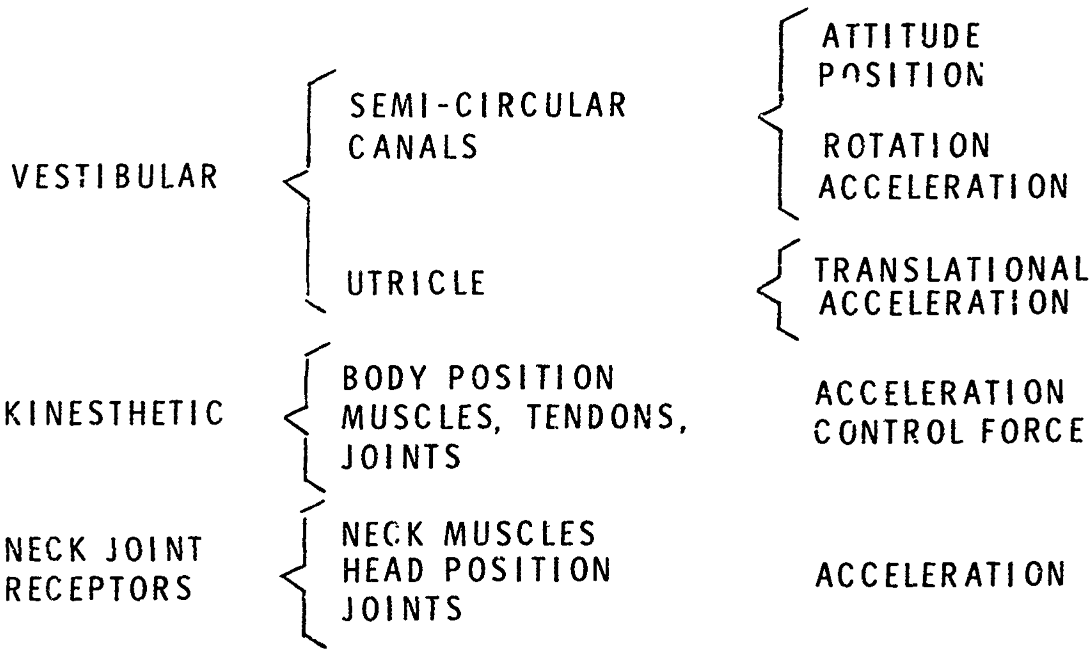


Figure 3. Motion Cues

that threshold increases for increases in velocity. An increase in duration of the visual scene lowers the threshold. Increasing the field-of-view or increasing illumination, decreases threshold (these two parameters are of particular interest because they are a vital consideration in effective utilization of the point light and wide-angle visual system in the NAVTRADEVCEN Visual Simulation Laboratory). The remaining are effects of the retinal area of the eye, and monocular or binocular condition at near distances.

In addition to the visual parameters, the motion and kinesthetic cues(2) to be considered are indicated in figure 3. These motion cues are essentially those of acceleration and changes in attitude or angular position. The principal source of motion sense is the vestibular apparatus which consists of two sets of sensors, one set located in each inner ear. Each set is composed of an angular sensor or semi-circular canal and a linear acceleration sensor called the utricle. The vestibular systems behaves as a stable platform which first, senses static and dynamic orientation of the head, and second, stabilizes the eye so that clear vision is possible in spite of head motions. The kinesthetic cues are derived by the operator from the movement of his limbs as he actuates his controls in the vehicle, or as the vehicle is exposed to changes in acceleration. The kinesthetic or control force cues and their important interaction, with the vestibular and visual sensors, have attracted interest only recently and little information has been published on it. Of even more recent interest are the neck muscles and head combination as a motion sensing apparatus.(1,2) These respond to acceleration with resulting changes in muscle tension as the supported head is moved and acts as a motion receptor. This, in turn, interacts with the vestibular system in a way that is also as yet not completely understood. These type of interactions appear to typify a new trend in which the combinations of sensory characteristics and simulator are considered as a unit rather than just the simulator by itself.

The classification of cues (whether they are primary, secondary conflicting or masking cues) depend on the responsive characteristics of the various sensors. For example, because of its frequency bandwidth characteristics the vestibular sensors have a faster response than the visual sensors. The kinesthetic control force cues produce even quicker responses. Because of this these sensors would be superior for the higher order motion of accelerations and rates of acceleration onset cues. The visual cues on the other hand are on the lower end of the frequency spectrum but are indispensable in detecting vehicle position and other predominantly visual cues.

As we will discuss later, some of the more recent techniques(4) for the combined motion and visual simulator will be to take advantage of the characteristic frequency bandwidth of the motion and visual sensors to simplify motion platform requirements. These will include electrical filtering and washout techniques for separating the visual and motion cues in accordance with their appropriate frequency bandwidth.

In these techniques the motion receptors of man are matched to the appropriate portion of his environment in order to avoid illusions in the form of disorientations or false perceptions. Illusions are related to the loss of visual reference, however, a major contribution to disorientations occurs in those situations where frequancies of the motion environment are lower than those of the sensor frequency spectrum. Thus, for example, the semi-circular canals would be incapable of detecting a very slow roll error. If the pilot corrects his error rapidly and the original roll was not perceived,

the pilot is forced to assume he has rolled in the opposite direction when, in fact, he is straight and level. Thus, in general, illusions may occur due to large motion excursions or slow continuous turns with prolonged mis-alignment with the inertial gravity vector. These illusions can take the form of diving when recovering from a turn, sensing a wrong tilt when in a skid, a nose high attitude during takeoff, and other illusions involving inversions, spirals, and spins.

Effects of motion sickness were reported with NTDC Device 2FH2, a fixed base cockpit and point light source wide-angle visual screen. Similar effects were reported on recent tests sponsored by the U.S. Army Aviation Material Laboratory on the Northrup wide angle point light source visual system. This particular system similar to the one with NAVTRADEVCEN Visual Simulation Laboratory, has inherent dynamic visual distortions which are also a probable cause of motion sickness. However, when motion cues were added, the occurrence of motion sickness was reduced drastically. In these cases it was the experienced pilots who became sick, due to lack of motion, but not the new trainee. This apparently was an indication of the habit pattern in utilizing motion cues. These particular phenomena were the basis for the incorporation of a motion platform with the point light source visual display installed in the Visual Simulation Laboratory. Other factors which may cause motion sickness are the previously mentioned lack of motion fidelity and poor optical performance.

NAVTRADEVCEN VISUAL SIMULATION LABORATORY POINT LIGHT SOURCE EQUIPMENT

Considerable effort has gone into the development of the point light transparency systems since about 1960. They are, in theory, capable of simulating the view from an operator aerial position of a two or three dimensional ground terrain in correct perspective without the use of sophisticated electronic equipment. Basically, this technique uses a point light source of high brightness which casts the "shadow" of a photographic transparency onto the wide screen surrounding the operator as shown in figure 4. The transparency is mounted on a servo-driven gimbal system, which translates and rotates with respect to the stationary point light source, for all six degrees of freedom, and portrays the motion of the simulated vehicle on the screen.

The relative position of the point light source to the transparency is analogous to the position of the actual vehicle with respect to the ground. This can be seen from the diagram in figure 5 by taking the ratio of similar triangles, one formed by the subtended scene and the other by the image on the transparency. The simulated altitude dimension "h" is subsequently found to be equal to the distance "d" from the point light source to the transparency times the transparency scale factor. Thus, it is possible to vary the simulated altitude in direct proportion to changing the distance between the light source and the transparency. It is also possible to change the transparency and scale factor depending on the altitude and scene resolution requirements of the mission intended for simulation.

An example of a visual scene from a transparency having three-dimensional models of transparent buildings, various structures and trees mounted on it is shown in figure 6. A scale factor of 100 to 1 is used for this transparency which gives an acceptable resolution for 3-D perspective missions close to the ground. For greater ranges in altitude and maneuverability a two-dimensional

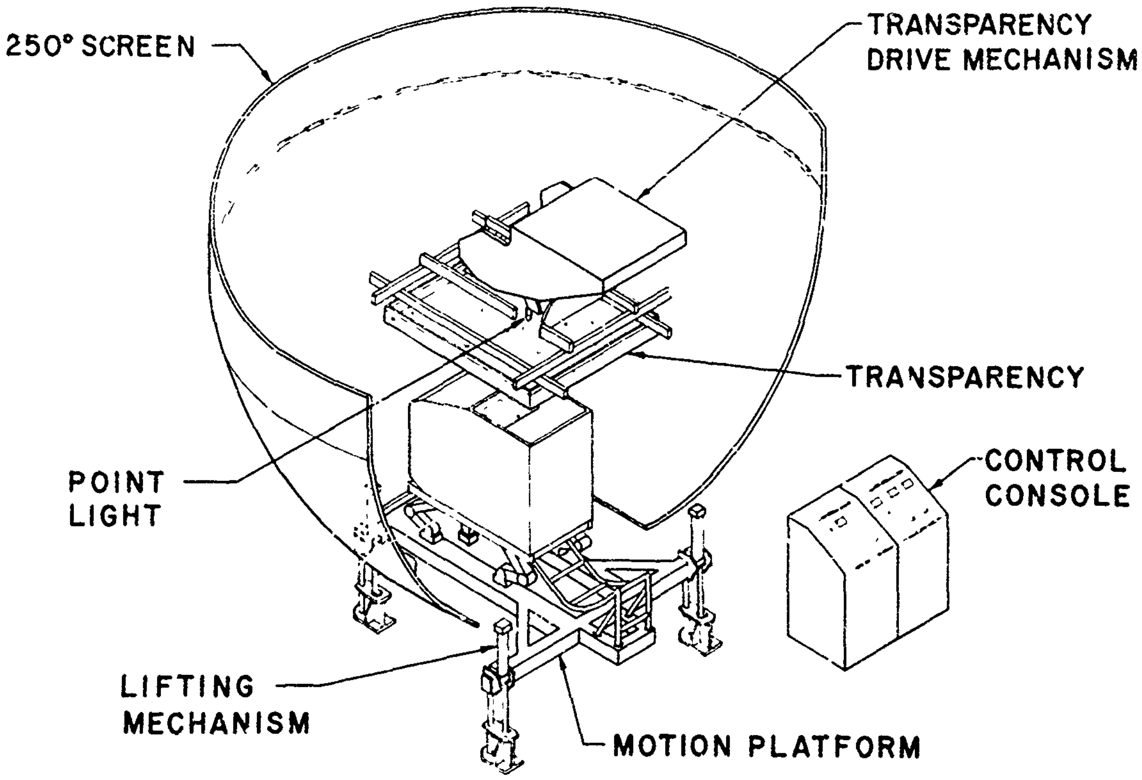
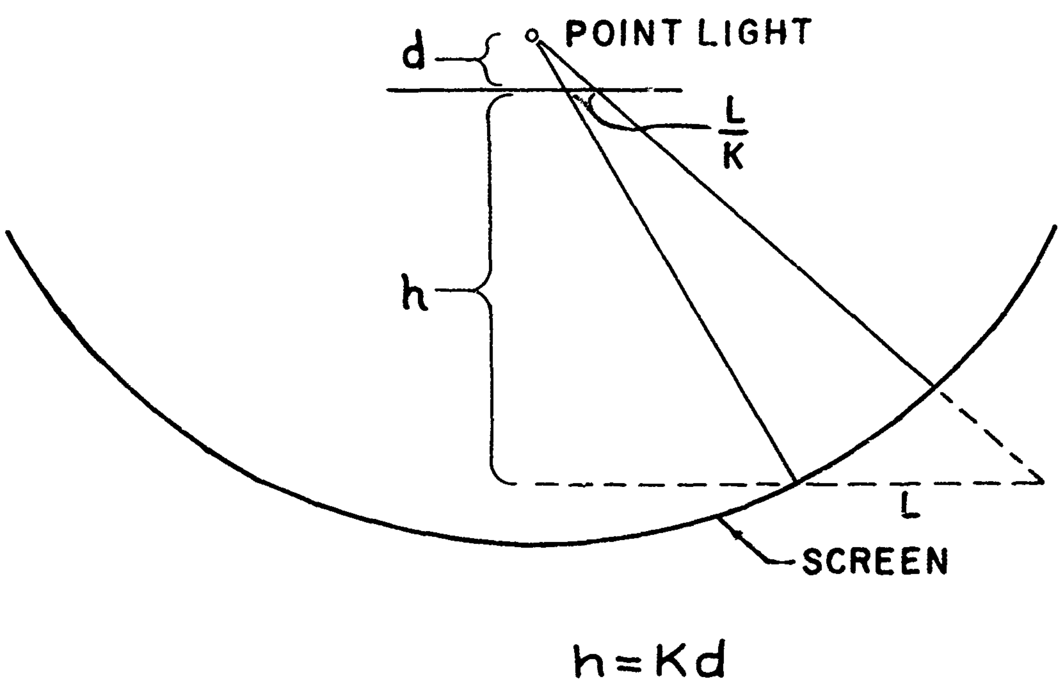


Figure . Point Light Source Visual System and Motion Platform



$$h = Kd$$

Figure 5. Point Light Source Scale Factor

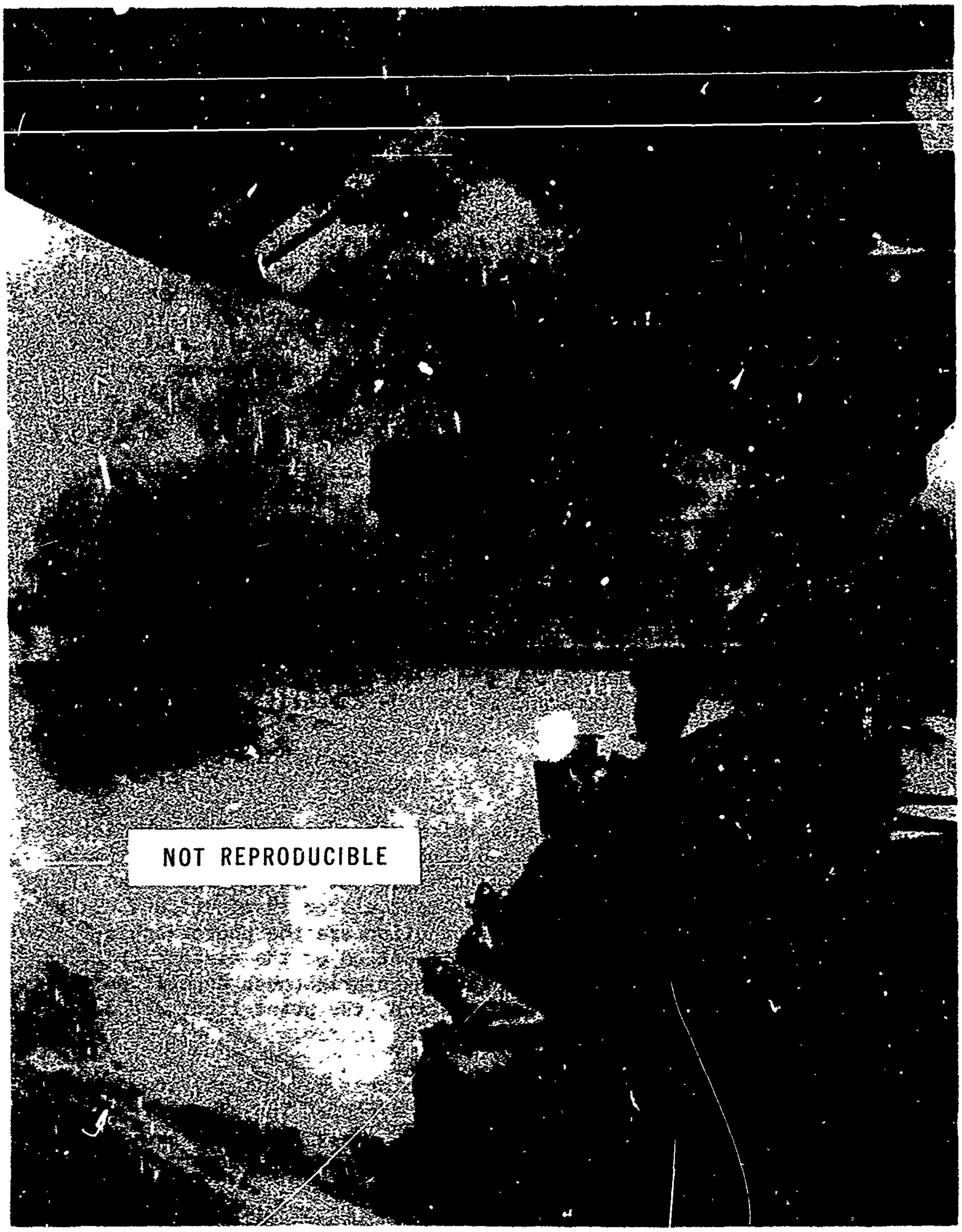


Figure 6. NAVTRADEVCEN Devide 2-FH-2 Point Light Source Helicopter Trainer

transparency is used with scale factors up to 2500:1 or larger. The photo of the scene, as shown, appears distorted since the camera used for taking the photo was located a considerable distance from the point light source location.

The NAVTRADEVCEN Visual Simulation Laboratory equipment indicated in figure 5 includes a point light source, a 250° wide screen, several semi-photographic color, and black and white transparency, a transparency drive mechanism, the hydraulic motion platform, hydraulic power supply, which is not shown, and the control consoles and associated electrical equipment. The motion platform is a compact design and is mounted on a hydraulic lifting mechanism. Quick disconnects are used to break the hydraulic lines so that the motion platform can be lowered onto a dolly and easily transported to another location, where it can be used with the wide-angle TV projection, for a future assault boat motion simulation. The motion platform was originally constructed by the NAVTRADEVCEN Laboratory Services Department from a Melpar design for Device 2F75 for a helicopter simulation project.

The motion platform shown in figure 7 has capability for $\pm 15^{\circ}$ pitch, $\pm 15^{\circ}$ roll, and $\pm 6''$ vertical translation. The motion platform features a booster actuator to balance out the static load. It also has an important feature - an adjustable point of rotation in pitch. This is important because the direction of pitch acceleration and the nature of the pitch motion cue is highly dependent on the point of rotation. This is accomplished by the combined actions of the two pitch and heave actuators, which can be pre-programmed to represent the point of rotation of the simulated aircraft. They also provide vertical translation when they operate in unison. The point of rotation in roll is fixed and it is independently actuated from pitch and heave.

IMAGE QUALITY PARAMETERS

The quality of the projected scene, which can affect operator performance, depends on the resolution, brightness, and distortion of the projected image. The most important factor affecting resolution is the size of the point light, which for the Visual Simulation Laboratory light source is about .004 of an inch diameter. Other factors affecting resolution are the photographic resolution of the transparency and the magnification or the distance between the light source and the transparency. The image brightness depends on the projection distance, screen gain characteristics, the point light optical system, and the total radiant energy of the light source.

The two parameters of resolution and brightness have limitations which are a characteristic of the point light source system. The distortion problems[3], however, are more general and would apply for any visual system where the observer's eye is displaced from the light source position. These consist of size, position, and velocity distortion.

As shown in figure 8, size distortion results, since the observer views the screen from a point, just below the transparency close to the point light source. The image, however, is not exact due to distortions which depend on geometrical relationship between the observer and the point light source

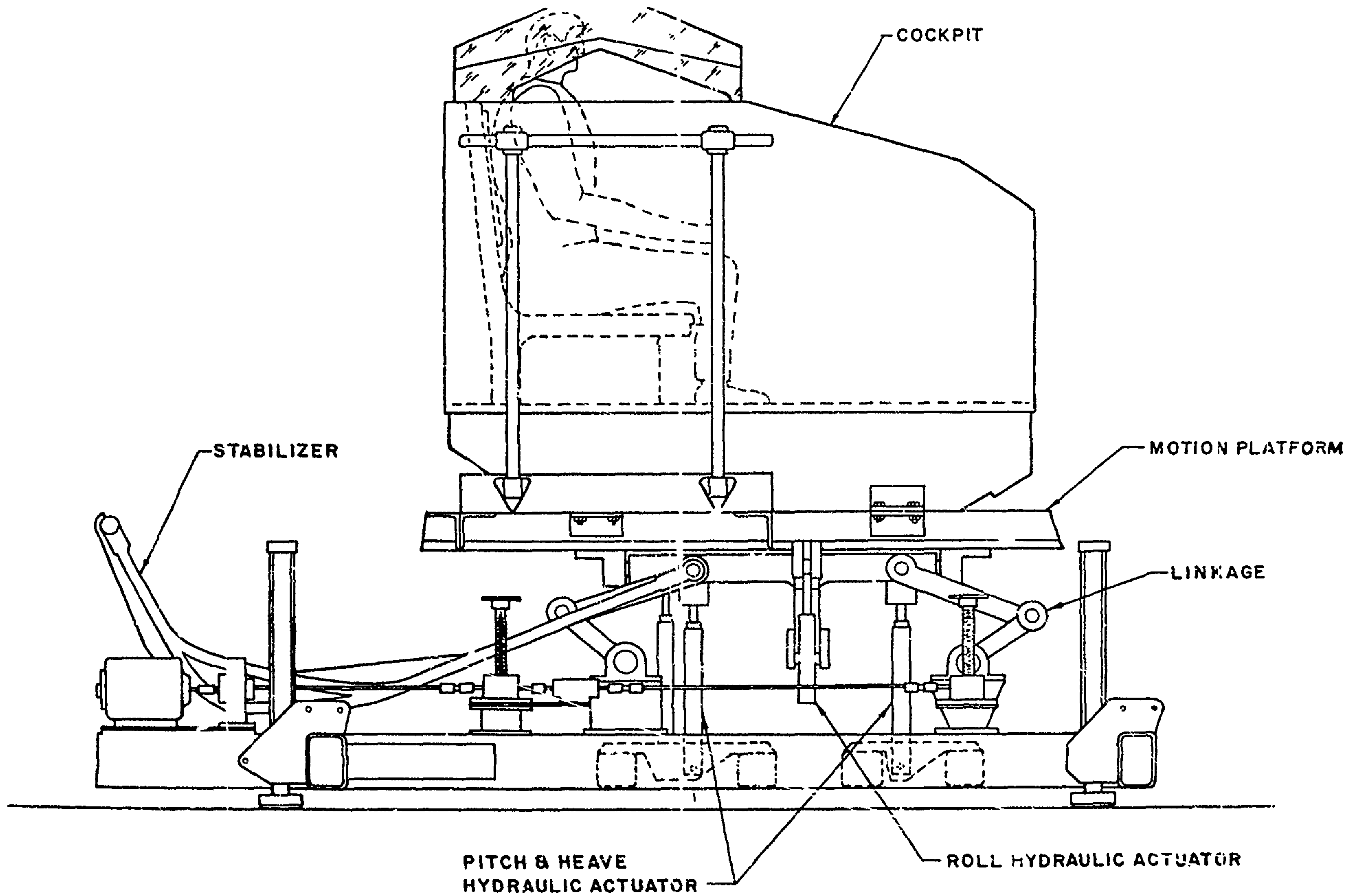
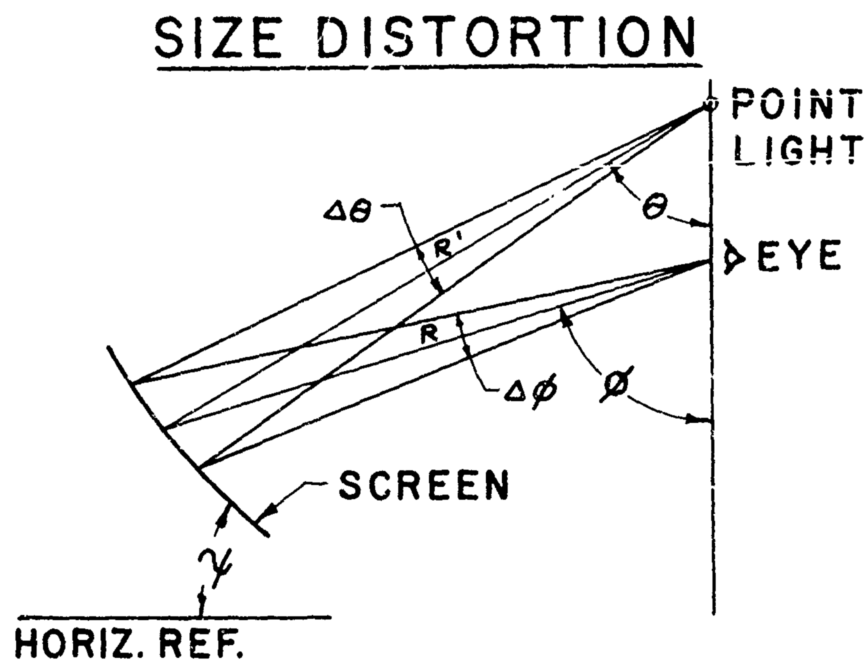


Figure 7. Motion Simulator



$$S.D. = 100\left(\frac{\Delta\phi - \Delta\theta}{\Delta\theta}\right) = 100\left[\frac{R'\cos(\phi-\theta)}{R\cos(\theta-\psi)} - 1\right]$$

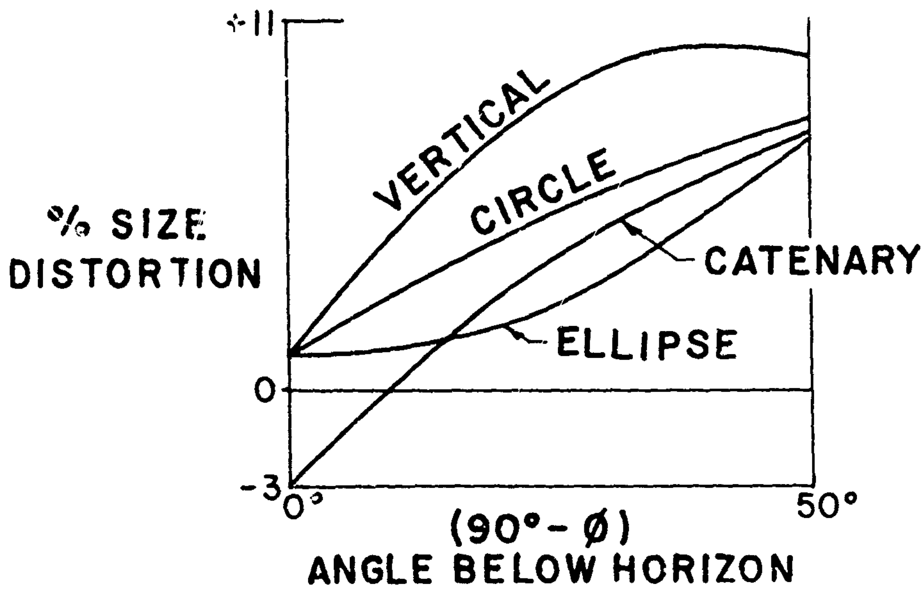


Figure 8. Image Quality Parameters, Size Distortion

as a function of the screen radius. This distortion is expressed as the ratio of the difference of the subtended angles and $\Delta\theta$. From the curves for this expression, the catenary and the ellipse screen contours show the least size error. It will be shown later, however, that the ellipse has other disadvantages due to dynamic distortions. In general, the distortion in size of the projected image is primarily dependent on the slope angle of the screen surface and in most cases less dependent on the eye positions.

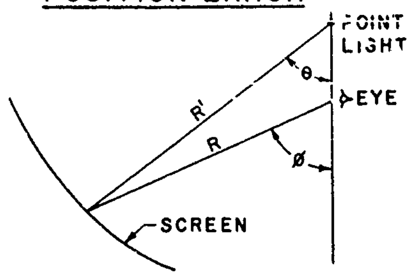
The error in the projected position, on the other hand, is a critical function of both the eye position and the screen shape as shown in figure 9. If the screen shape is such that the error in position varies across the screen, undesirable velocity and acceleration errors will occur. Since the eye is located below the point light, the image appears at a higher elevation than the true elevation. The horizon then appears to be above the observer resulting in the effect of traversing the inside of a bowl. The expression for position error can be obtained from simple geometry and is expressed as the difference between the angles ϕ and θ. We find the error is a maximum at 90° from the vertical and minimum of zero error at 0° from the vertical. This bowl effect is minimized by placing the projected horizon at eye level and using a separate sky projector.

A more serious error is the rate of change of the previous position error indicated in figure 10. This is the velocity error across the screen causing projected straight lines to bend or flex as the scene moves. The equation for the percent velocity error is obtained by taking the derivative of the position error and is shown as a function of the angle θ, the radius R and the rate of change of R with respect to θ and thus is a function of the shape of the screen.

The graph of velocity error is shown for circle, ellipse, v[illegible]al, and catinary cross section. The catinary curve appears the most att[illegible]ive, since it doesn't show a rapid rate of change in velocity error across the field. In addition, the catinary was a very simple shape to construct by using sections of appropriate lengths of flexible sections of material whose distributed weight would generate the catinary curve. For these reasons this screen shape was selected for the Visual Simulation Laboratory.

With the imaging errors minimized to a satisfactory degree, the main problems remain with scene resolution and screen luminance. As shown in figure 11, only a portion of the light from the point light penetrates the transparency and the supporting plexiglass. The amount transmitted depends on the angle of incidence. Thus, the brightness varies across the screen with the highest brightness below about 40° incident angle and then decreasing with partial light reflection until the light is totally reflected at about 85° incident angle. This blackout occurs near the horizon and thus illumination for the sky and horizon is required through a separate sky projector. As will be shown later, this decrease in brightness is compensated by the increase in resolution due to the increase in range distance. Due to the variation of brightness across the screen a high gain specular screen such as aluminous paint could not be used. The screen used in the Visual Simulation Laboratory is a retro-reflective glass bead with a cloth backing, having a gain of about 2.6; the use of a retro-reflective screen tends to reflect more light back to the viewer in the cockpit and thus minimizes the detrimental effects of the off normal illumination. Screen brightness measurement from .1 to .3 foot lamberts were obtained with the

POSITION ERROR



POSITION ERROR; $\phi - \theta = \tan^{-1}\frac{d\sin\phi}{R + d\cos\phi}$

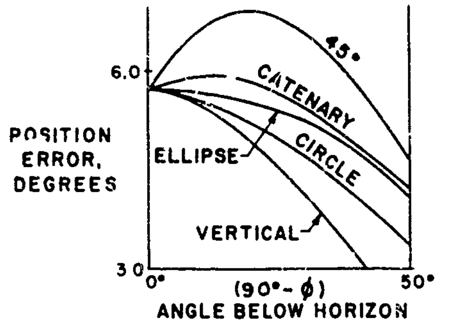
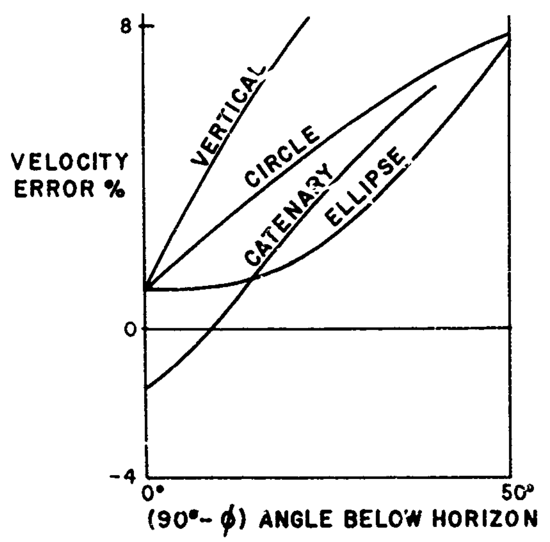


Figure 9. Image Quality Parameter Position Error

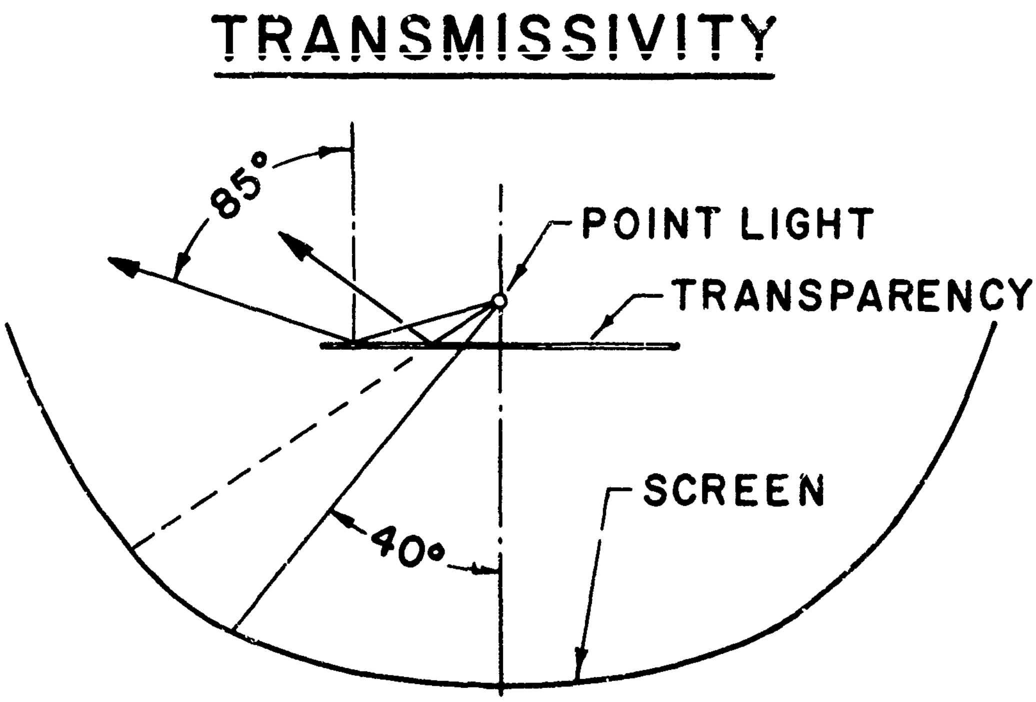
VELOCITY ERROR



VELOCITY ERROR;

$$100\left(\frac{\dot{\phi}}{\dot{\theta}} - 1\right) = 100\left[\cos\theta - \frac{dR}{d\theta}\frac{\sin\theta}{R}\right]\frac{1}{(R^2 - \sin^2\theta)^{1/2}}$$

Figure 10. Image Quality Parameter Velocity Error



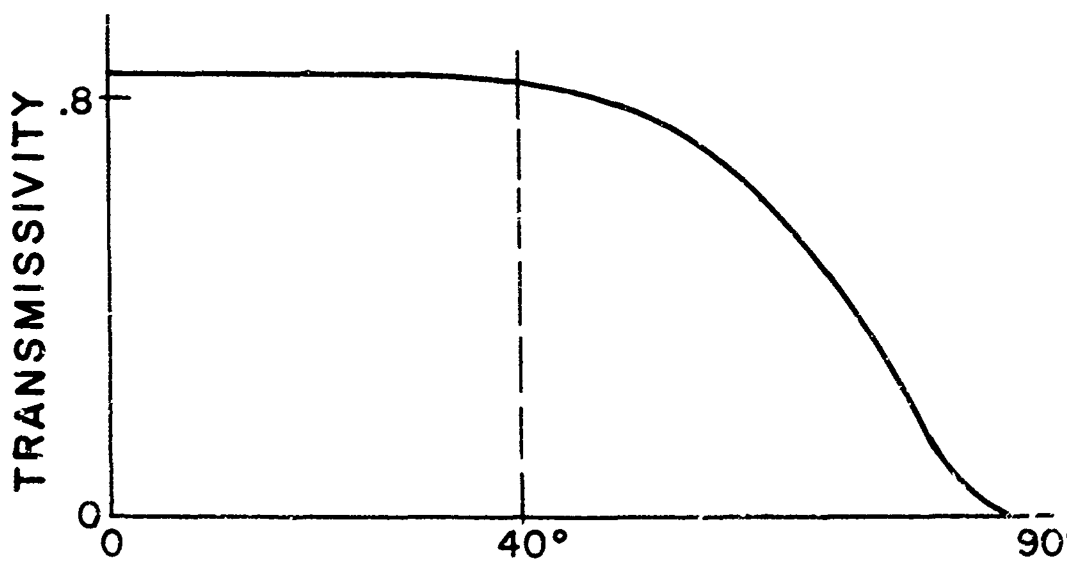


Figure 11. Image Quality Parameter
Transmissivity

laboratory equipment which is expected to be sufficient for the dark adapted eye for intended experimental purposes. The resolution of the point light source has been recently measured. It is shown in figure 12 to compare favorably to a television system at higher slant ranges. It can be seen that angular resolution for the point light system increases with a decreasing slant range. That is, the resolution deteriorates rapidly when the point light approaches the transparency or the slant range decreases below about 1/4 of its maximum. This is attributed to the effect of the size of the point light source on resolution. This also means that, when the transparency images are further away from the point light, the improvement in resolution compensates or offsets the previously mentioned loss of brightness with angle of incidence with the transparency. It is also noted that changing the transparency scale factor will shift the resolution curve. Thus, comparisons with other systems may require that these curves must be normalized to a common scale factor. It should be pointed out that the resolution indicated in figure 12 is available for the point light system with a greater wide angle capability than the television system.

MOTION PLATFORM REQUIREMENTS

Motion platforms in general, as stated earlier, cannot duplicate the translational motion of the aircraft exactly because of its limited motion capabilities. Thus, after an acceleration cue is sensed the motion must be washed out, that is it must be decelerated below the threshold of the operator's motion sensor before the platform reaches its limiting stops. If we consider the velocity of the Visual Simulation Laboratory motion platform during a uniform deceleration we see from figure 13 that it forms a parabolic envelope which is the limiting displacement of the motion platform cues. This envelope determines when the washout is to occur in accordance with what the velocity of the platform is at a certain position. The constant K would be selected so that the deceleration would be below the threshold that a person can detect. We can see from the curves for displacement, velocity and acceleration that the washout takes a considerable portion of the available distance. The washout is accomplished by using a switching circuit which is analogous to the platform motion equation. In this equation the constants K_1 equals 1 or zero so that when the platform is tracking the motion signals from the computer, $K1 = 0$ and only the tracking terms remain. When the velocity reaches a value which corresponds to the position as determined by the washout envelope, $K1$ then equals 1, and the first tracking term is cancelled leaving the washout term.

In the case of the pitch and roll for the normal landing type problems the attitude or angular cues could be represented fairly closely. For this reason the present Visual Simulation Laboratory configuration includes washout only for the heave or vertical translation direction. The roll cockpit motion will include provisions for side force cues and return to neutral during a coordinated turn. The visual display will provide all the remaining apparent translational motions including the vertical motion independent of the cockpit heave. The visual display will be stationary during the pitch mode with the cockpit providing the pitching cue. In the roll direction, the visual display will move relative to the cockpit to give a true apparent roll cue.

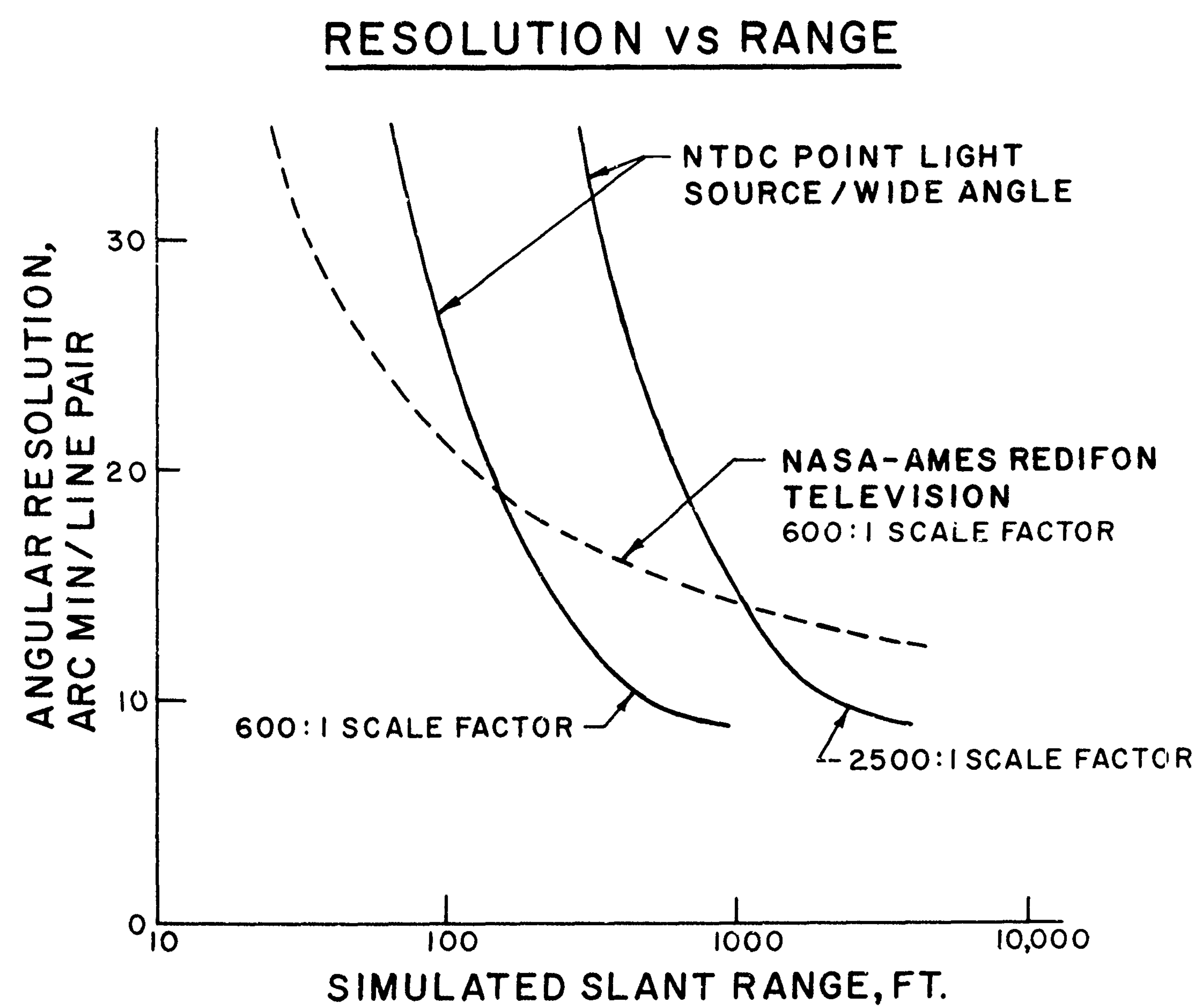
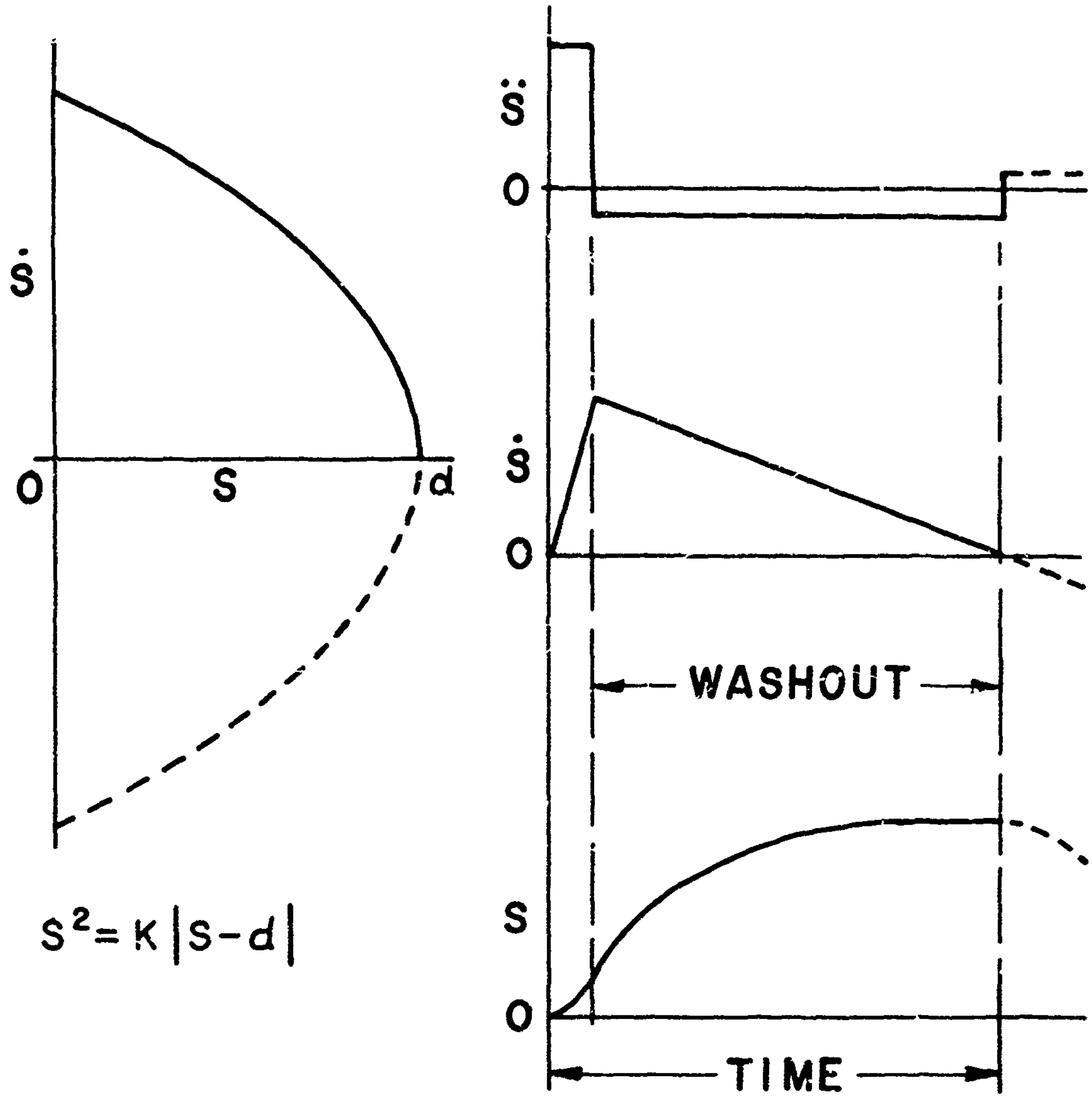


Figure 12. Image Quality Parameter
Resolution VS Range

MOTION CUES



$$\ddot{S} = K_1 \dot{q} - \dot{W}_G$$

$$S = \int \left[\dot{S} K_{sn} + K_1 \left(-\dot{S}_n + K_2 \sqrt{S'_n - d} \right) \right] dt$$

Figure 13. Motion Platform Requirements, Motion Cues

The roll displacement will be made to rotate as a function of roll rate. This is a satisfactory method to provide a quicker motion response to compensate for the lag of the equipment using only computer signals which represent the true motion. This also means that the platform will return to neutral position when the roll rate is zero and when the displacement signal gradually decays to zero by the roll circuitry. The separate visual system meanwhile continues the illusion of a roll attitude.

Figure 14 indicates the possible forces resulting from a turn. For a coordinated turn which would not have a skid or side slip, the gravity vector side component is balanced by the centrifugal force during the turn which accompanies roll. Hence, the platform displacement would be zero and the visual system would continue the illusion of roll. However, should the pilot maneuver result in a net side force as in an uncoordinated turn, then an additional motion cue for a prolonged steady state force is required. The technique here, as mentioned earlier, is to use the gravity vector to produce the side force by rolling the simulator to the appropriate side depending on whether the force is outward or inward and then depend on the dominance of a strong visual cue to overcome the angular sensing mechanism of the canals of the inner ear.

Thus, we see that the motion platform does not provide an exact duplication of the aircraft orientation as well as the motion due to inherent limitations of the motion platform. However, accurate cues are required and the combination of the cockpit motion and visual display must indicate an accurate orientation of the aircraft. For the roll direction, as shown in figure 15, the visual display must therefore move in such a way that the relative motion between the motion platform and the visual display motion system produces an apparent aircraft motion, as viewed by the operator in the cockpit. On this basis the platform equation of motion, as previously shown, combines with the true motion signals from the computer to determine the drive signals to be provided to the visual display.

RECENT VISUAL/MOTION TECHNIQUES

A relatively new technique[4] which is currently used on other point light visual and cockpit motion systems, and under consideration by the NTDC Visual Simulation Laboratory for future modification is illustrated on the block diagram of figure 16 for the roll and simulated lateral directions. This system uses a high pass filter as indicated by the transfer function to introduce the high frequency components to the motion platform. The low frequency components to the visual system are obtained by taking the difference between the computer displacement signals and the filtered high frequency signals. This is in accordance with the human factor requirements mentioned earlier where the frequencies below the motion sensor threshold is avoided for the motion platform. Thus, the time constant used in the transfer function is selected experimentally to match the human motion sensor. The filters also provide the required washout of the motion cue. Phase lead compensation is introduced to the motion and the visual system by adding the velocity signals to the displacement signals. As with the displacement signals the high frequency components of velocity signal are directed to the motion platform and the low frequencies to the visual system. The true apparent motion, as discussed previously, is obtained by maintaining the current relative motion between the visual system and the cockpit. The lateral accelerations are introduced through a low pass filter. This provides

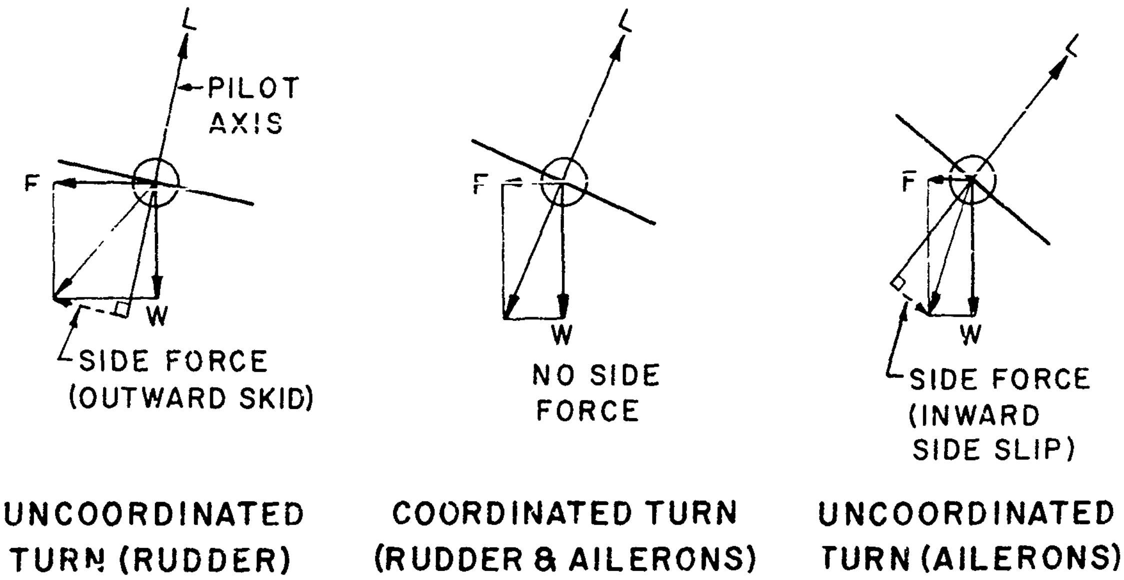
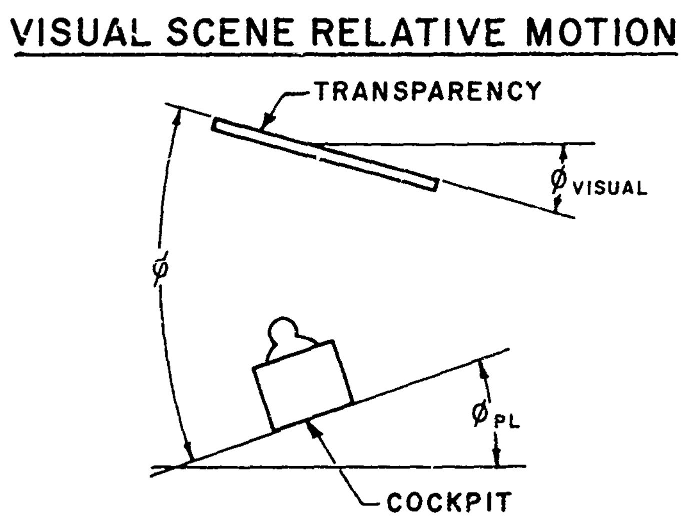


Figure 14. Pilot Turning Forces



$$\phi_{PL} = \dot{\phi} + \theta + \lambda$$

$$\phi_{VISUAL} = -\phi_{PL} + \phi_{VISUAL/PL}$$

WHERE $\phi_{VISUAL/PL} = \phi$

ϕ = COMPUTER SIGNAL (APPARENT DISPLACEMENT)

$$\phi_{VISUAL} = K_1\phi - \dot{\phi} - \lambda$$

Figure 15. Motion Platform Requirements
Roll Direction

LATERAL MOTION SYSTEM-VISUAL DISPLAY INTERFACE

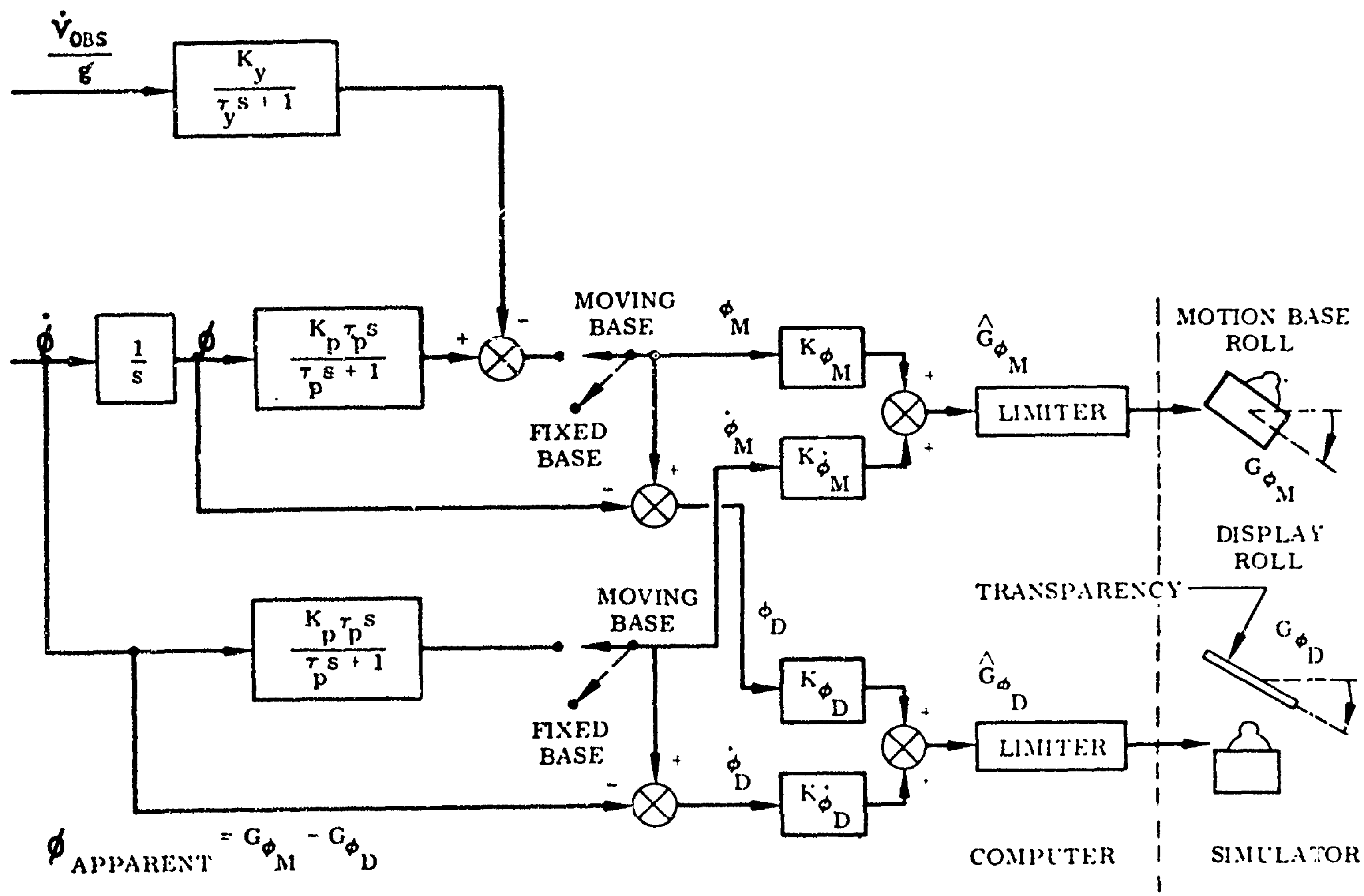


Figure 16. Block Diagram Recent Visual/Motion Techniques

a signal which will rotate the cockpit for a simulated side force by utilizing the gravity vector. In this case, the time constant is such that the high frequency components are filtered out so that the angular sensing ear canals are not affected, but the lower frequency linear utricle sensors will provide the prolonged acceleration effect during a side slip or a simulated uncoordinated aircraft turn.

COMBINING VISUAL AND MOTION SYSTEMS

In order to combine the motion and visual systems, the response characteristics of both the motion platform and the visual motion device must be matched to avoid visual distortions and false cues. Dynamic tests were performed on the NTDC Visual Simulation Laboratory equipment to determine the frequency response for both visual and motion systems. The results of these tests as shown in figure 17 indicated a drastic difference between the two systems for the pitch and roll directions. For example, as shown on the chart the 3 db cutoff for the visual basic motion device in roll was only .2 Hz while it is a respectable 1.1 Hz for the cockpit motion platform.

This unsatisfactory difference between the motion and visual system is shown again in figure 18 on the frequency response and phase lag curves for the roll direction. In an effort to make the two systems compatible, by making their phase lag vs frequency curves nearly identical, a study was made to determine the means to improve the roll and pitch visual system frequency response. This study indicated that the pressure drop in the 70 feet of pressure and return hydraulic lines from the hydraulic drive station to the transparency drive actuators were excessive and subsequent test data was obtained as shown on the next figure to verify the hypothesis.

If we compare the test data with slopes generated by the representative linear equation of motion as shown in figure 19, we see that the slope of $N = 1$ for the velocity exponent indicates that viscous portion of the curve dominates the loading. A slope of 2 for the inertia exponent is at a much higher frequency and therefore was not a dominant term. The hydraulic line size was subsequently increased which improved the frequency response by a factor of 4 from .2 Hz to .8 Hz. This would satisfy the requirement for the visual frequency bandwidth to match the bandwidth of the motion platform. Further electrical adjustments or compensation methods would be the next step to make a closer matching of the visual and motion drive systems.

An important point here is that the original specifications for the visual system would have been inadequate to meet the requirements for the present intended purpose of the equipment. That is, the maximum velocities and accelerations were specified and reported in the acceptance tests for the original equipment but the mechanical frequency considerations were neglected in the specifications.

As a recommendation, specifications for motion drive systems should include frequency response and phase lag information as well as a complete description of performance as shown on the nomograph in figure 20. The performance curve shown as an example is for the motion platform in the

ROLL	$\pm 15°$
PITCH	$\pm 15°$
HEAVE	± 6 IN
ACCELERATION	$\pm \frac{1}{2}$ G
HYDRAULIC PSI	800 OPERATIONAL
	3000 TEST

Figure 17. Motion Platform Characteristics

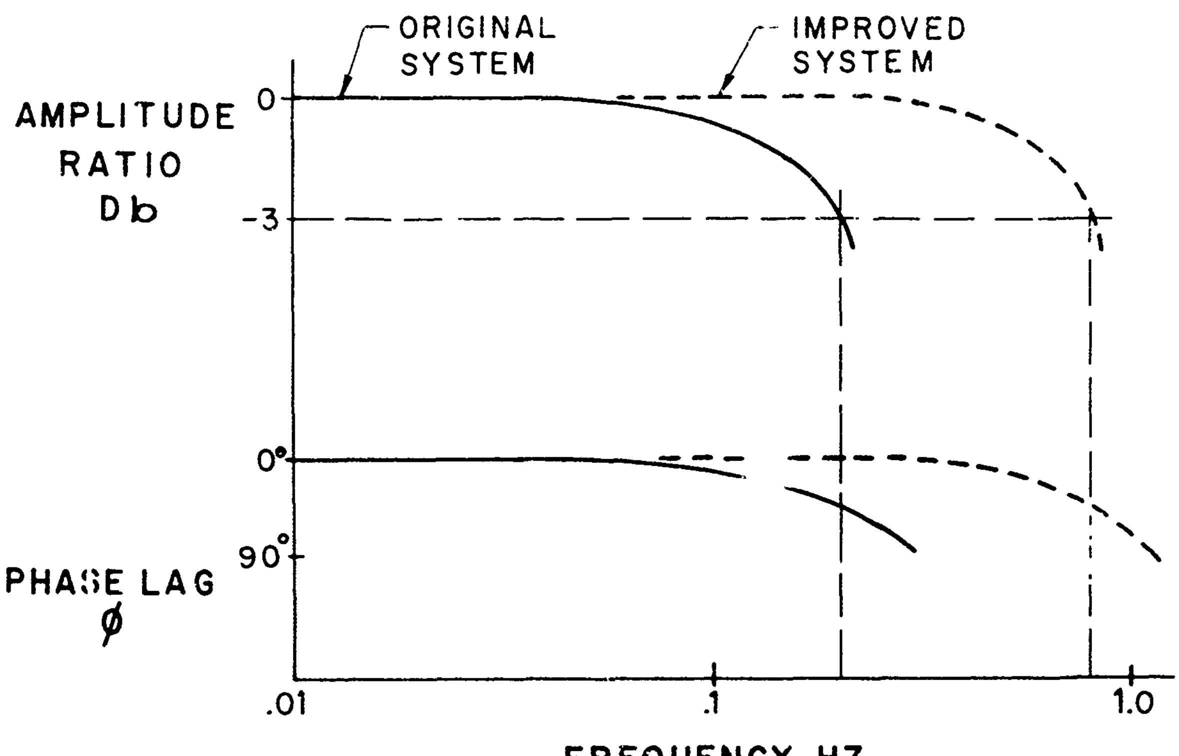
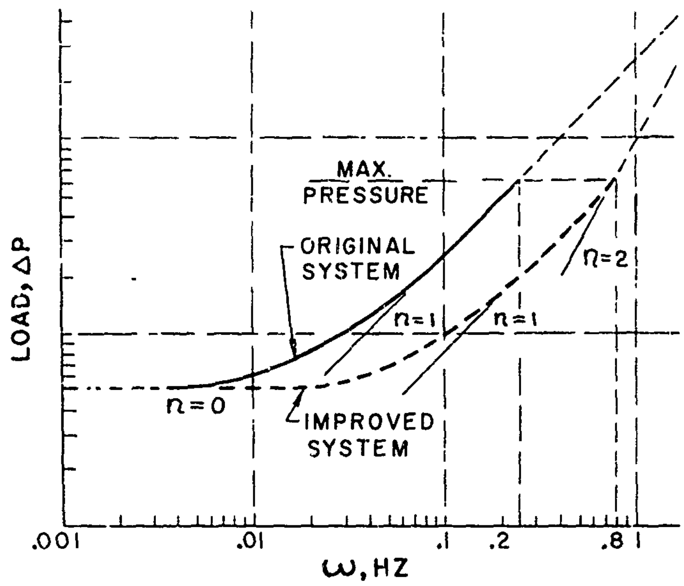


Figure 18. Roll Frequency Response



$$\Delta P = Ma + Bv + Kx$$
$$= M\ddot{x} + B\dot{x} + Kx$$
$$= (M\omega^2 + B\omega\angle 90^\circ + K)x_{MAX}\sin\omega t$$

Figure 19. Visual Display Mechanism Load

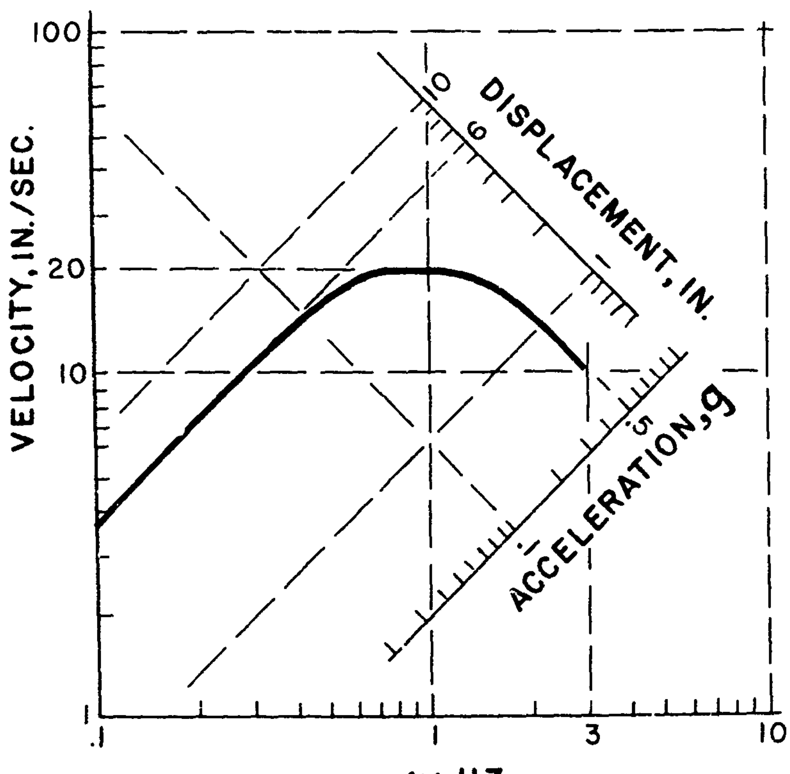


Figure 20. Motion Platform Performance

Visual Simulation Laboratory. This curve defines the limiting envelope of displacement, velocity and acceleration requirements at all points within its frequency bandwidth. This would be preferred to than just specifying maximum amplitude of displacements, velocities and accelerations without frequency considerations as has been apparently done in the past.

EXPERIMENTAL TEST PROGRAM

The present and future test and evaluation programs (except for platform motion) are based on recommendations from the various studies on NTDC Device 2FH4. The completion of the testing for the present task is scheduled for reporting in Dec of 1971. Validity tests of the T-28 Flight Simulator, will establish its perceptual fidelity to the aircraft it simulates less the display. Qualitative indications of the instruments response to cockpit control inputs have been completed. Quantitative tests of the instrument response for lateral and longitudinal stability have been started. The second item is Validity of Flight Simulator-Visual Display Characteristics. This includes dynamic testing of the visual mechanism for frequency response to meet the T-28 performance requirements which have been completed. The combination test will involve a pilot flying the aircraft to a contact flight landing. The criterion here will be pilot performance in making visual landings on a runway in accordance with rating techniques to be set forth in a report being prepared by Mr. Moe Aronson, Head of the NAVTRADEVCEN Visual Simulation Laboratory. The tests to determine design parameters for visual displays for specific missions would include experimental designs devised by the Human Factors Laboratory. The next item Validity of Motion Platform Characteristics include dynamic tests which have been completed. Further threshold acceleration measurements and threshold experiments are intended. And finally Specific Motion and Visual interactions will cover effects of visual distortion due to eye displacement to platform motion. This would also include effectiveness of math model of simulated motion cues.

The proposed tests beyond the present task would continue with tests to determine design parameters and would involve effects of reducing the level of brightness, and effects of varying contrast ratios of selected targets. The tests to determine application of training of specific visual tasks would cover (1) resolution or recognition of checkpoints for low altitude navigation (2) effects of transparency scale on low altitude observation, and air to surface attack missions (3) adequacy of forward visible missions (4) effect of limitation on visual display displacements in pitch and roll, (5) scoring of surface attack mission (6) training techniques studies based on initial flight conditions and (7) visual display for creating illusions of aircraft spins. The Specific Motion and Visual Interactions would also be continued from the present task to include determinations of amount of motion necessary to prevent conflict between visual and motion cues and to determine the extent of improvement of pilot performance with addition of motion.

SUMMARY AND CONCLUSION

In summation we can state that the recent efforts for combining the visual and motion systems indicate the trend for considering the man and machine as a system unit.[5] This is shown by the block diagram of the pilot and the simulator in figure 21. It is seen that the pilot has three

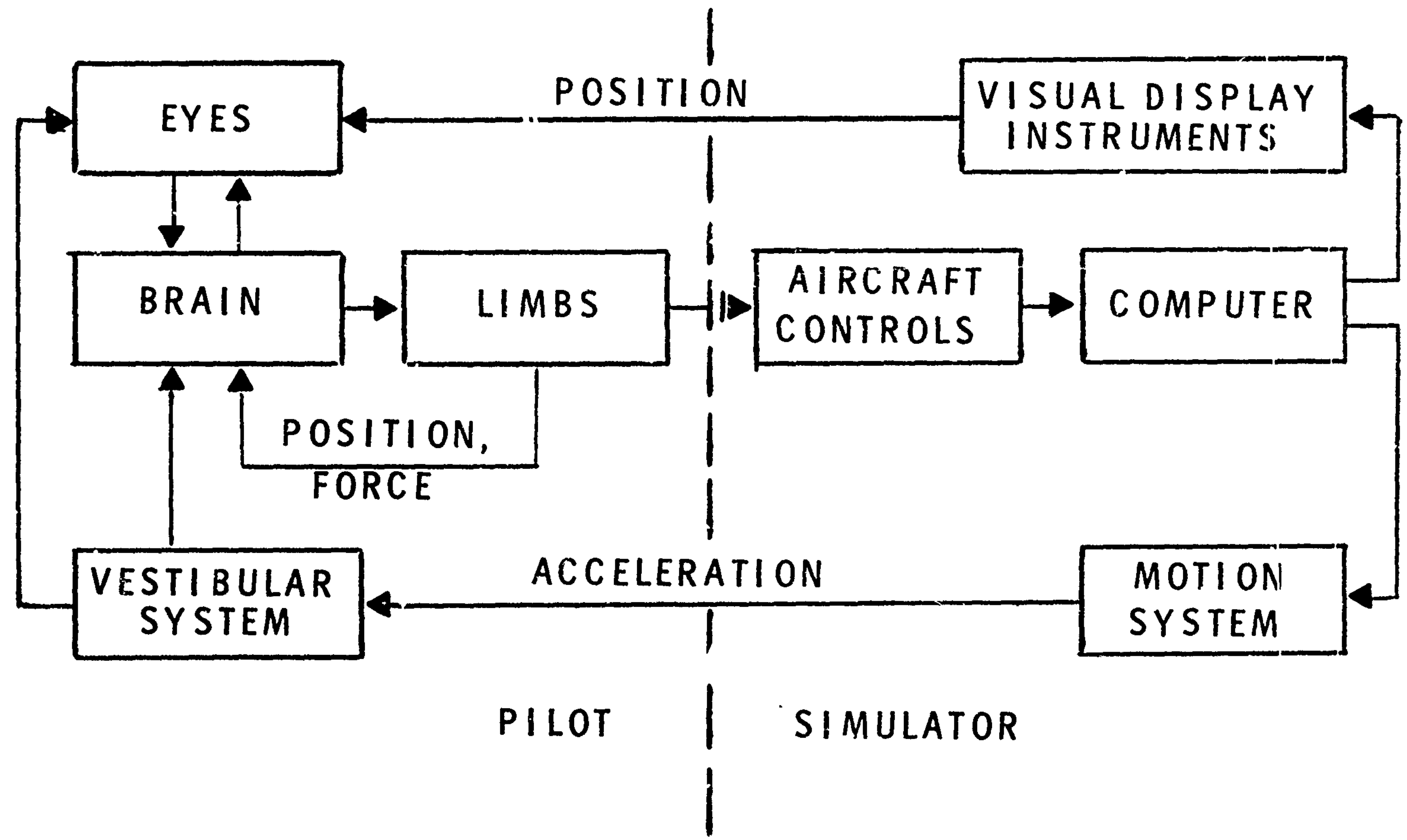


Figure 21. Block Diagram of Pilot and Simulator

main input sources for information: First, his eyes, which provide the main input. The information from his instruments and the visual scene tells him his attitude, position in space, and to a lesser extent, the rate of change of these variables. Second, his limbs, which tell him the position of the vehicle controls, the force he is exerting on them and the external forces on them. Third, the vestibular system which tells him when he is subjected to acceleration. And it also stabilizes the eyes during motion.

If a sudden disturbance is applied to the simulator he is immediately alerted through the vestibular system and is thus prepared to detect any visual or instrument changes. The visual indication will be delayed due to the inherent lag of the visual response, but the motion cue permits a faster pilot response for applying a correction to the pilot control. This brings another feedback loop into operation which tells the pilot how much he has moved the controls. An interaction occurs here since the aircraft acceleration generated by the controls displacement is sensed by the vestibular system and the pilot knows the correction is taking effect even though the instrument is indicating the result from the previous disturbance. In the case of the kinesthetic cues the pilot has even a quicker response to acceleration and has the added possible advantage, where the pilot can distinguish, between an aircraft response to outside disturbances and the aircraft response to his control movements. The pilot is thus able to predict what is going to happen to the simulator by means of these feedback loops, and build up pattern habits similar to those used in the aircraft. Whereas, in a simulator without motion, the pilot is deprived of the fast acceleration feedback and so he builds up an entirely different habit pattern.

In conclusion we may state that the point light source system is presently the only 360° non-programmed visual system in existence. Recent NAVTRADEVCEN reports have investigated multichannel TV systems as a potential technique for wide angle presentation but as yet no hardware has been built. The resolution and brightness is recognized to be the major drawbacks to the training utilization of the visual point light system, though not detrimental to the research tasks outlined. Plans have been underway for a new point light source optical system at the NAVTRADEVCEN Visual Simulation Laboratory which would provide improved uniformity of screen luminance and increased brightness by a factor of about four, and improved display resolution. In addition, laser technology has progressed so that laser light will be a possible light source in the near future. This could permit an extremely small spot with considerably more brightness than with conventional light sources. Finally, there appears to be a definite advantage for the addition of motion to visual systems, where the mission requires pilots to acquire habit patterns, similar to those obtained through actual aircraft training. However, considerably more basic knowledge is still required on the interactions of combined motion and visual cues for accurate representation of an operational situation.

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PROGRAM

Tuesday, 15 February 1972
SESSION I

Dr. James J. Regan, Chairman
Head, Human Factors Laboratory
Naval Training Device Center

0900 Open Conference

0905 Introduction
Captain F. H. Featherston, U.S.N.
Commanding Officer, Naval Training Device Center

0915 Presentation on Naval Training
Vice Admiral M. W. Cagle, U.S.N.
Chief of Naval Training

0945 Conference Theme
Dr. H. H. Wolff, Technical Director and Conference General Chairman
Naval Training Device Center

1000 Transfer of Instrument Training and the Synthetic Flight Training System
Dr. Paul W. Caro
Human Resources Research Organization, Division 6 (Aviation)

1025 Coffee Break

1045 Effects of Training Situation Analysis on Trainer Design
Mr. N. R. Holen
McDonnell Aircraft Company, St. Louis, Missouri

1110 Quantitative Task Analysis and the Prediction of Training Device Effectiveness
Dr. A. Mirabella and Mr. G. R. Wheaton
American Institutes for Research

1130 Lunch

Tuesday, 15 February 1972
SESSION II

Mr. George Derderian, Chairman
Head, Physical Sciences Laboratory
Naval Training Device Center

1300 Open Session II

Session II (continued)

1305 A Modified Model for Visual Detection
Dr. R. C. Sugarman, Mr. H. B. Hammill, Mr. J. N. Deutschman
Cornell Aeronautical Laboratory, Inc.

1325 Semiconductor Laser Applications to Military Training Devices
Mr. Albert H. Marshall
Physical Sciences Laboratory, Naval Training Device Center

1350 Digital Radar Land-Mass Display Simulation
Mr. R. A. Heartz
General Electric Company, Daytona Beach, Florida

1415 Design and Production of Antireflection Coatings
Mr. Denis R. Breglia
Physical Sciences Laboratory, Naval Training Device Center

1440 Coffee Break

1500 140° Close Approach Optical Probe for Visual Simulation
Mr. Albert Nagler
Farrand Optical Company, Inc.

1525 A New Assessment of Wide-Angle Visual Simulation Techniques
Mr. Moses Aronson
Head, Visual Simulation Laboratory, Naval Training Device Center

1550 Special Performance Lenses for Eidophor Real-Time Dynamic
Full-Color Large-Screen Displays
Mr. H. C. Hendrickson
Philco-Ford, Western Development Laboratories

1615 Session II ends

1915 Social Hour, Hemisphere Lounge

2015 Banquet, Ballroom of the Americas
Toastmaster: Mr. E. X. Blaschka
Head, Program Control Department, Naval Training Device Center

Address by the
Honorable Robert A. Frosch
Assistant Secretary of the Navy for
Research and Development

Wednesday, 16 February 1972
Session III

Mr. Edward H. Grace, Jr., Chairman
Head, Field Engineering and Support Department
Naval Training Device Center

0830 Configuration Management-An Asset to Training Devices Production and Navy Support
Mr. John J. Regan
Modification and Maintenance Engineering Division
Naval Training Device Center

0855 The Universal Display Panel
Mr. Donald E. Reed
Electrical and Mechanical Trainers Division
Naval Training Device Center

0920 Real-Time Projected Displays
Mr. R. E. Thoman
General Dynamics Corporation, Electro Dynamic Division

0945 Built-In Test (BIT) for Training Devices
Mr. L. A. Whalen and Mr. M. P. Gerrity
Maintenance Engineering Division, Naval Training Device Center

1010 Coffee Break

1030 The DRAGON Antitank Missile System Training Equipment and Gunner Training
Mr. C. J. Whitman
McDonnell Douglas Astronautics Company

1055 Introduction
Colonel M. H. Mierswa, Sr., U.S.A.
Commanding Officer, U.S. Army Training Device Agency

1100 Innovations in the Army's Training Program
General Ralph E. Haines, Jr., U.S.A.,
Commanding Officer, U.S. Continental Army Command

1130 Innovations in Land Combat Training
Mr. B. L. Sechen, Deputy Director of Army Projects
U.S. Army Training Device Agency

1200 Lunch

Wednesday, 16 February 1972
Session IV

Mr. Emerson J. Dobbs, Chairman
Head, Sea Requirements and Plans Department
Naval Training Device Center

1315 Open Session IV

1320	Introduction Colonel J. M. Terry, Jr., U.S.M.C. Marine Corps Liaison Officer Naval Training Device Center
1325	Marines-Past, Present, and Future Lieutenant General Ormond R. Simpson, U.S.M.C. Deputy Chief of Staff (Manpower)/Director of Personnel Headquarters, Marine Corps
1345	Surface and Subsurface Program Requirements Mr. E. J. Dobbs Naval Training Device Center
1410	Undersea Warfare Training Device Requirements for the Next Quarter Century Mr. Alan J. Pesch, Chief, Man/Machine Systems Electric Boat Division, General Dynamics Corporation
1435	The Farrand Ground Effects Projector Mr. J. A. La Russa Farrand Optical Company
1550	Coffee Break
1520	Advances in Sonar Audio Simulation Mr. Edward J. Wrobel ASW Tactics Trainers Division, Naval Training Device Center
1545	Multiple Oscilloscope Trace Generation for Analog Computers Dr. Klaus W. Lindenberg and Mr. Paul E. Speh Florida Technological University
1610	Electromagnetic Compatibility of Training Devices Mr. R. N. Hokkanen Maintenance Engineering Division, Naval Training Device Center
1630	Session IV ends

Thursday, 17 February 1972
Session V

Mr. Victor G. Hajek, Chairman
Head, Air-Warfare Department (ASW/Environmental)
Naval Training Device Center

0830	Needed: A Strategy for the Application of Simulation in The Curricula Proposed Training Systems Dr. Thomas R. Braby Land/Sea Trainers Applications Div., Naval Training Device Center

Session V (continued)

0855 Tradeoff Criteria for Specification of Prime or Simulated Computers in Training Devices
Mr. A. E. Mergy
Hughes Aircraft Company

0920 Instructor Console Instrument Simulation
Mr. I. V. Golovsenko and Mr. J. L. Booker
Naval Training Device Center, Computer Laboratory

0945 Status of Computer-Generated Imagery for Visual Simulation
Mr. M. G. Gilliland
General Electric Company, Apollo Division

1010 Coffee Break

1030 Computer-Assisted Instruction (The SFTS as a Computer Controlled Training Device)
Mr. D. E. Trundle
Singer Company, Link Division

1055 Safety Aspects in Aviation Physiological Training Devices
Mr. Hans W. Windmueller
Land/Sea Trainers Modification Division
Naval Training Device Center

1130 Lunch

Thursday, 17 February 1972
Session VI

Mr. Harold Rosenblum, Chairman
Deputy Director of Engineering
Naval Training Device Center

1300 Trends in Naval Aviation Training
Captain D. W. Nordberg, U.S.N.
Head, Air Training Section, Chief of Naval Operations, U.S. Navy

1325 Air Program Requirements
Mr. Arnold E. Allemand, Jr., Head, Air Requirements and Plans Department, Naval Training Device Center

1350 Application of Advanced Simulation Technology to Pilot Training
Mr. J. F. Smith and Mr. D. W. Simpson
Singer Company, Link Division

1415 Automated GCA-Final Approach Training
Dr. J. P. Charles and Mr. R. M. Johnson
Logicon, Incorporated

1440-1445 Closing Remarks, Captain F. H. Featherston, U.S.N., Closing Conference, Dr. H. H. Wolff